U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB80-130461

Intact or Unit-Kernel Sweet Corn

(U.S.) Science and Education Administration, Albany, CA

Prepared for

Industrial Environmental Research Lab -Cincinnati, OH

Oct 79

United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/2-79-193
October 1979

PB80-130461

Research and Development

EPA

Intact or Unit-Kernel Sweet Corn

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/2-79-193		PB 80 130461

4. TITLE AND SUBTITLE
Intact or Unit-Kernel Sweet Corn

5. REPORT DATE
October 1979 issuing date

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
G.H. Robertson, M.E. Lazar, D.F. Farkas, J.M. Krochta, J.S. Hudson, F. Pao, B. Terrell, J. Farquhar

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Western Regional Research Center
USDA-SEA-FR
800 Buchanan St.
Berkeley, CA 94710

10. PROGRAM ELEMENT NO.
1BB610

11. CONTRACT/GRANT NO.
R-804597-01-1

12. SPONSORING AGENCY NAME AND ADDRESS
Industrial Environmental Research Lab. - Cinn, OH
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Technical 1976-79

14. SPONSORING AGENCY CODE
EPA/600/12

15. SUPPLEMENTARY NOTES
Co-sponsor: American Frozen Food Institute
McLean, VA 22101

16. ABSTRACT
This report evaluates process and product modifications in canned and frozen sweet corn manufacture with the objective of reducing the total effluent produced in processing. In particular it evaluates the proposed replacement of process steps that yield cut or whole kernel corn with process steps that yield intact or unit kernel corn. When compared to a conventional cutting process with a yield of 40 to 33 parts per 100 parts of corn in husk, the processing of intact kernels resulted in corresponding waste reductions of 85% to 94% (based on chemical oxygen demand per pound of product) and yield increases of 5% to 26%. Sensory comparisons showed that regardless of the variety or method of preservation, intact kernel samples were preferred by a larger percentage of the panel (paired preference rating) than the cut controls. In addition, intact kernels were shown to be 14.5% higher in fiber content, 100% greater in fat content, and 5% to 16% higher in protein. The application of a preferred frictional method for producing intact kernels is probably subject to varietal development of sweet corn with weak attachment to the cob and strong adherence between adjacent kernels.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Food Processing Vegetables Wastewater	Corn Process Modification	13/B

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release to public	UNCLASSIFIED	70
	20. SECURITY CLASS *(This page)*	22. PRICE
	UNCLASSIFIED	A04-A01

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

* U.S. GOVERNMENT PRINTING OFFICE 1979-657-146/5487

EPA-600/2-79-193
October 1979

INTACT OR UNIT-KERNEL SWEET CORN

by

G. H. Robertson, M. E. Lazar, D. F. Farkas,
J. M. Krochta, and J. S. Hudson
Western Regional Research Center
U.S. Department of Agriculture
Berkeley, California 94710

and

F. Pao, B. Terrell, and J. Farquhar
American Frozen Food Institute
McLean, Virginia 22101

Grant No. R-804597-01-1

Project Officer

H. W. Thompson
Industrial Pollution Control Division
Industrial Environmental Research Laboratory
Corvallis, Oregon 97330

This project was conducted
in cooperation with
American Frozen Food Institute
McLean, Virginia 22101

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report discusses research work on a processing modification for sweet corn. A small-scale system evaluated the methods of removing the kernels of corn intact from the cob. This would significantly reduce the quantity of organic material in the effluent wastewater and result in greater yields. For further information on this project contact the Food and Wood Products Branch, Industrial Pollution Control Division, Industrial Environmental Research Laboratory-Cincinnati.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

Intact or unit kernels of sweet corn were substituted for conventional or cut kernels in an attempt to reduce the copious amounts of liquid waste produced during processing. A small-scale, simulated processing line was set up to evaluate processing advantages and disadvantages, to establish methods for producing intact kernels, and to generate samples by which the product quality could be evaluated and compared to the conventionally prepared product. Sweet corn varietal suitability for intact kernels was also evaluated.

When compared to a conventional cutting process with a yield of 40 to 33 parts per 100 parts of corn in husk, the processing of intact kernels resulted in corresponding waste reductions of 85% to 94% (based on chemical oxygen demand per pound of product) and yield increases of 5% to 26%.

Sensory comparisons showed that regardless of the variety or method of preservation, intact kernel samples received higher mean scores (hedonic ratings) or were preferred by a larger percentage of the panel (paired preference rating) than the cut controls. In addition, intact kernels were shown to be 14.5% higher in fiber content, 100% greater in fat content, and 5% to 16% higher in protein.

One method for producing intact kernels was preferred because the kernels it produced yielded lower waste loads and were judged to be higher in quality. However, the application of this method is probably subject to varietal development of sweet corn cultivars with loose kernels. Processing considerations would favor development of varieties with weak attachment to the cob and strong adherence between adjacent kernels.

This report was submitted in fulfillment of Grant No. R-804597-01-1 by the American Frozen Food Institute under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period 15 July 1976 to 15 July 1978, and work completed as of 15 July 1978.

CONTENTS

Foreword iii
Abstract iv
Figures vi
Tables viii
Abbreviations x
Acknowledgments xi

1. Introduction 1
2. Conclusions 2
3. Recommendations 3
4. Experimental Materials and Procedures 5
5. Results and Discussion 19

References 52

Appendices

1. Waste Indices 53
2. Preliminary canning studies 54

FIGURES

Number		Page
1	Field map indicating location of 1976 plantings and estimated direction of prevailing wind (p.w.)	5
2	First and second plantings for 1977	6
3	Third through seventh plantings for 1977	6
4	Schematic of "hole-saw" unit	8
5	Front and side view of element used to longitudinally split ears of sweet corn.	9
6	Apparatus used to split ears of corn.	9
7	Schematic of textured-surface process for intact kernels . .	10
8	Schematic of smooth-surface process for intact kernels. . .	11
9	Smooth-surface frictional removal of sweet corn kernels. . .	12
10	Cross section illustrating corn split section position with respect to frictional removal element.	15
11	Cross section of a 45 x 3 kernel displacement test	17
12	Cross-section of a 90 x 1 or 90 x 2 kernel displacement test.	18
13	Liquid waste strength of cut and intact-kernel samples for washing A and blanching B.	20
14	Waste strength for cut-kernel samples.	21
15	Kernel damage resulting from contact with frictional element.	24
16	Yield increase of intact over cut kernels for freshly prepared kernels.	25
17	Yield increase of intact over cut kernels for washed kernels.	25

18	Yield increase of intact over cut kernels for frozen kernels.	26
19	Ideal yield of intact sweet corn	26
20	Density flotation of sweet corn.	31
21	The role of kernel position relative to friction surface in successful kernel removal.	32
22	Freshly prepared, unwashed samples of cut and intact sweet corn.	34
23	Frozen and thawed samples of cut and intact sweet corn (var. Stylepak).	35
24	Frozen and thawed samples of cut and intact sweet corn (var. Golden Happiness)	35
25	Frozen and thawed samples of cut and intact sweet corn (var. Golden Jubilee)	36
26	Corn cross sections and individual kernels of (l to r) Golden Happiness, Golden Jubilee, and Stylepak.	38
27	Adaptation of USDA interpretive guide illustrating pulled kernels and cut kernels in canned and frozen corn	39
28	Kernel rupture during 45 x 3 (B) and 90 x 1 or 90 x 2 testing (A)	43
29	Rates of removal of sweet corn from Golden Happiness (A), Golden Jubilee (C), and Stylepak (B) by friction with a moving, smooth, neoprene surface	48
30	Schematic free-body diagram for displacement of sweet corn kernels	49

TABLES

Number		Page
1	Process for sweet-corn experiments	14
2	Washer and blancher liquid-effluent strengths	22
3	Contributions to effluent strength.	22
4	Suspended solids collected during washing of cut and intact-SS kernels (moisture-free basis).	23
5	Approach to complete or ideal kernel removal by smooth-surface and textured-surface processes	27
6	Ear location of kernels not detached by frictional technique. .	28
7	Mass recovery of sweet corn after each process step	29
8	Mean kernel weight distributions for freshly prepared samples.	29
9	Mean frozen kernel weight distributions	30
10	Intact kernel yield comparison for textured and smooth processes	30
11	Predicted losses of intact kernels from intact-HS kernel mixtures by flotation in NaCl solutions.	31
12	Static coefficient of friction (η_s) for clean and contaminated neoprene surfaces.	33
13	Mean incidence of glume tissues in freshly prepared intact-TS kernel samples.	37
14	Absolute change in distribution from washing intact kernels . .	37
15	Mean hedonic ratings for cut (normal) and intact-SS sweet corn frozen in 1976	40
16	Mean hedonic ratings for frozen and canned, cut and intact-SS sweet corn prepared during 1977.	40

17	Paired preference ratings for intact and cut sweet corn	41
18	Fiber and total nitrogen in cut and intact sweet corn	41
19	Total amino acid content increase for intact sweet corn relative to cut	42
20	Maximum total force per kernel measured during kernel displacement	43
21	Sweet corn yield changes due to heat (5 min, 100°C steam) preconditioning of ears to effect kernel loosening.	44
22	Thermal processing to alter strength of kernel attachment. . .	45
23	Maximum component forces measured during kernel displacement. .	47
24	Comparison of per-kernel force by actual 45 x 3 tests to force by computed 45 x 3 tests based on component abscission and interkernel frictional forces in 90 x 1 or 90 x 2 tests . .	51
A-1	Correlation of waste indices (I) with total organic carbon measurement.	53
A-2	Recommended stationary-retort processing conditions.	54
A-3	Recommended agitated-retort processing conditions.	55

ABBREVIATIONS

Analytical Measures

BOD	-- Biological oxygen demand
COD	-- Chemical oxygen demand
N	-- Force in newtons
SS	-- Suspended solids
TOC	-- Total organic carbon
TS	-- Total solids
SD	-- Standard deviation

Kernel types

Intact - DC	-- Intact sweet corn kernels produced by deep cutting using commercial cutter.
Intact - HS	-- Intact sweet corn kernels produced by extremely deep cutting using experimental hole-saw cutter.
Intact - SS	-- Intact sweet corn kernels produced by friction between kernels and a moving smooth surface.
Intact - TS	-- Intact sweet corn kernels produced by friction between kernels and a moving textured surface.

Heat penetration parameters in canning

j	-- Time lag before the heating curve assumes a straight line on semilog paper.
fc	-- Time required for the straight line part of the cooling curve to traverse one logarithmic cycle.
fh	-- Time required for the straight line part of heat penetration curve to traverse one logarithmic cycle.
f_2	-- Time required for the straight line portion of the heat penetration curve following a break in the initial heating curve to traverse one logarithmic cycle.
X_{bh}	-- Time from corrected zero time of the process to the break in the heat penetration curve.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Harold Thompson, U.S. Environmental Protection Agency Project Officer, for his guidance on this project. In addition, we would like to thank the following personnel of the American Frozen Food Institute, who provided Administrative assistance: Joanne Cox, Elaine Carter, Jean Bohannon and Ray McHenry. We also wish to acknowledge the following persons and organizations for their assistance. Professor Walton C. Galinat (University of Massachussetts) and David Galinat who provided sources of Golden Happiness seed. The University of Illinois Foundation (Champaign, Ill.) provided Illini Xtra Sweet seed and Rogers Brothers Seed Co., Nampa, Idaho provided Golden Jubilee seed. Dr. Charles Geise and Dr. William F. Hagan (San Leandro, Calif.) and Ray Boone and Albert Erojo (Gilroy, Calif.) of Del Monte Corporation, Agricultural Research assisted in the horticultural aspects of the project. Don Corlett and Marty Fischler of of Del Monte Corporation (Walnut Creek, Calif.) provided C-enamel cans. Jay Unverferth, Christina Merlowe, Larry Lewis, and Richard Farrow of the National Food Processors Association (Berkeley, Calif.) performed chemical analyses and thermal studies, and prepared canned samples. Mike Haney (Rochester, Minn.) and Joe Ohler and Jim Albrecht (Chicago, Ill.) of Libby, McNeill and Libby provided assistance with and loan of corn processing machinery. Dave Pahl of the Northwest Food Processors Association (Portland, Ore.) surveyed the northwest canning and freezing industry regarding their practices and interest. Bob Gallion (Yakima, Wash.) of Libby, McNeill, and Libby, Paul Cover of the United Co.(Westminster, Md), Leslie Vadas and Jerry Smith of Food Machinery Corporation (San Jose, Calif.) and Alvin Randall of the Wisconsin Canners and Freezers Association (Madison, Wisc.) provided special assistance and encouragement of our objectives. José Perrotte (Brazil) assisted in developing equipment prototypes, and Dante Guadagni (Western Regional Research Center) supervised the sensory analyses.

SECTION 1

INTRODUCTION

Sweet corn processing effluent is a large contributing source of the total liquid wasteload originating from vegetable processing in the United States. Sweet corn is estimated to contribute 50 million kgs of BOD or 20% of the BOD from all vegetable processing sources (1). Much of this loading occurs through process water contact with the cut surfaces of individual corn kernels. These cut kernels are produced by forcing husked ears of corn endwise against stationary or rotating knives. The washed kernels are either canned or blanched and frozen as "whole kernel" corn (2,3) or they are macerated and then canned in a mixture with cut kernels as cream-style corn (4).

The substitution of intact or unit kernels was proposed earlier (5) as a means of reducing the effluent loading. Intact kernels are separated from the cob tissues at the natural abscission layer between kernel and cob, do not have a cut surface, and completely contain the kernel juices or "milk", thereby preventing transfer of these juices to the process water. These authors found the effluent-reducing potential for manually produced intact kernels to be about 80% for washing and blanching, and the yield improvement potential to be approximately 20% on a per-kernel basis.

The research reported here describes the continuation of the evaluation of intact-kernel sweet corn. It includes a detailed evaluation of the wasteload characteristics of the different kernel styles, evaluation of different methods for producing intact kernels, characterization of a limited number of sweet corn varieties with respect to their suitability for intact-kernel producing processes, and sensory comparison of canned and frozen samples of cut and intact corn to assess consumer reaction.

SECTION 2

CONCLUSIONS

The liquid wasteload from sweet corn processing that originates during washing and blanching can be drastically reduced by substitution of intact kernels for cut kernels. In theory, methods that effect detachment of intact kernels without rupture or other damage to the kernel can virtually eliminate the wasteload of processing waters.

The recovery of a substantial amount of additional corn solids is another advantage of the intact kernel as opposed to the cut kernel. Although solids recovery may differ in a commercial-scale device, this factor is likely to continue as a strong incentive for intact-kernel preparation methods.

Results of controlled sensory tests are added incentives for the substitution of intact for cut kernels. Strong preferences were expressed for intact frozen corn, and less strong, but significant preferences were indicated for intact canned corn. Preferences were based on flavor and texture. Intact corn was found to have more lipid material and slightly more fiber than the cut comparison.

Several methods can successfully produce intact kernels. However, when factors such as kernel quality and kernel separability are accounted for, techniques that apply friction to kernels and cause initial kernel separation at or near the natural separation or abscission zone appear to be the most successful. These methods are subject to the requirement for new materials handling methods when applied to split sections of ears and are sensitive to ear position with respect to the friction surface. The quality of the frictional contact greatly influences the quality and success of the kernel detachment event.

Of two frictional methods applied, a technique using a smooth friction-developing surface offered the advantages of continuous cleaning capability and control over the friction surface quality.

Strength of kernel attachment to the cob plays an important role in the success of frictional removal methods. Kernels with very high strengths of attachment can be difficult to detach before rupture of the kernel occurs. Most varieties tested had kernel detachment strengths that enabled successful kernel removal. However, since the detachment strength varied over wide limits, varietal selection will be an important factor to the successful production of intact kernels.

SECTION 3

RECOMMENDATIONS

1. Additional evaluation of the waste reduction potential of intact kernels by monitoring the washing and blanching operations is unnecessary. However, waste loads from the washing of small kernel samples can be used to index the extent of damage originating from a given experimental kernel-producing method.

2. The wide differences in kernel attachment strength that were identified in the testing of a very small population of sweet corn varieties indicate that opportunities do exist for breeding selection for this characteristic. A wider examination of the currently available varieties should be conducted to identify currently suitable types and/or identify genetic material for future breeding selection.

3. There remains a need for a study of factors related to the ease of kernel removal such as the development of pericarp strength and the maturation of abscission tissues. Factors that can be imposed to accelerate the kernel abscission and weaken the kernel attachment should also be examined.

4. Close contact between the breeding community and researchers involved with machine invention, design, and development is strongly urged, since the design of the kernel removal process and equipment depends on the nature of the sweet corn. If a very loosely attached kernel can be developed, methods such as the hole-saw technique should be reconsidered, since cob tissue adhering to kernels might then be amenable to removal by a tumbling or abrasive milling.

5. Further development of the smooth belt process described herein should be pursued. In particular, automatic methods for handling split ear sections and for presentation of split sections to the frictional surface should be investigated. Alternatively, methods for handling sweet corn ears from which several rows have been removed should be investigated. Such a development would enable estimation of equipment size and production rates.

6. As soon as the mechanical problems have been overcome, larger test packs for consumer, focus panel, or market studies should be initiated with an interested canner or freezer or a representative association. Field testing with varieties and under conditions normally encountered in corn producing areas should also be evaluated.

7. An ultimate goal of this work, a workable in-field or side-of-field process is difficult to evaluate without completion of recommended research, but a preliminary design study might be a useful exercise.

8. The extension of the unit kernel concept to the marketing of fresh corn may be an interesting opportunity. Fresh, refrigerated, intact kernels have keeping and eating qualities that should be evaluated relative to corn-on-the-cob. Advantages would include greatly reduced shipping bulk and transportation costs.

Kernel-detachment-testing recommendations.

9. The ear-sample to ear-sample uniformity of the corn should be controlled. This could be achieved by field selection and use of "prime" or first ears only and by controlled maintenance of individual plants through a technique such as drip irrigation.

10. The genetic integrity of the corn should be maintained. This would be achieved by homogenous plantings isolated from contaminating varieties.

11. The component of interkernel friction and the related loosening by adherence should be more effectively eliminated by applying a 90 x 1 test to ears from which alternate kernels have been cut away.

12. The measurement procedure could be improved by measurement of both x- and y- force components of force applied to kernels, by measurement of the dimensions and location of the abscission, and by measurement of the energy of abscission rather than the maximum force required.

13. The role of abscission altering agents other than heat should be investigated. Chemical or biochemical agents which alter the abscission process may reduce the net detachment strength. Indeed, the nature of the abscission of kernels at this stage in their development has not been investigated.

SECTION 4

EXPERIMENTAL PROCEDURES

RAW MATERIALS

Sweet corn for these studies was grown during 1976 and 1977 on irrigated land in Gilroy, Calif., by subcontract to the Agricultural Research Division of the Del Monte Corporation. The varieties Golden Jubilee and Stylepak were grown as representative of commercial processing sweet corn. The glumeless Golden Happiness and the sugary Illini Xtra Sweet were also grown.

During both years, sweet corn was planted in the late spring. On each date, at least two rows of each of two varieties were planted. The dates and field arrangements are shown in Figure 1, 2 and 3. Seed was planted at a rate to yield a 20-cm interplant and a 76-cm inter-row spacing. All of the seed was pretreated to insure a high germination rate, but no precautions were taken to prevent insect or bird infestation of the growing plants. Harvest of mature sweet corn began in August and continued until early October.

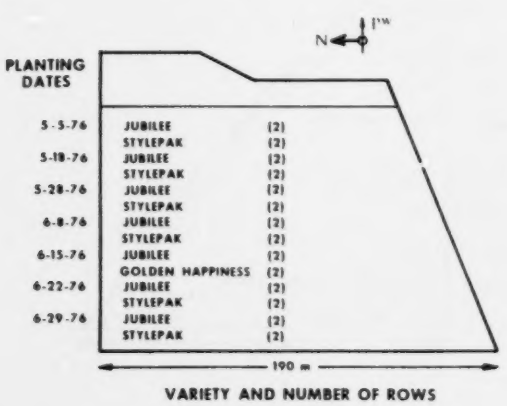


Figure 1. Field map indicating location of 1976 plantings and estimated direction of prevailing wind (p.w.).

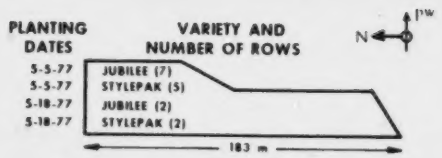


Figure 2. First and second plantings for 1977.

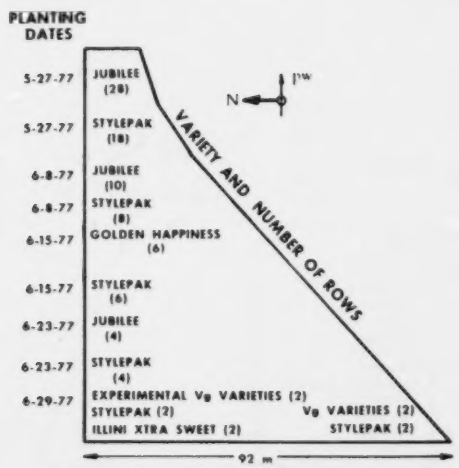


Figure 3. Third through seventh planting for 1977.

The fresh market variety Vanguard (Asgrow Seed Co) was available before the processing season. This variety was grown, hydrocooled, and iced by Alonzo Farms, Dixon, Calif. and obtained in Dixon or from a local wholesale produce market.

PROCESSING METHODS

Sweet corn maturity was monitored as moisture content of machine-cut kernels produced from a field sample of 10 or more "prime" or first ears. Harvest of sweet corn at processing maturity of 74% to 70% moisture was restricted to corn from one planting only. Sweet corn was harvested manually, transported by truck to Albany, Calif., composited to eliminate picker bias, divided into sublots of 16 to 130 kg and either husked in a commercial husking machine (1976) or husked manually (1977). The ears of each sublot were trimmed to exclude insect, bird, and microbial damage. Sublots of trimmed corn then were delivered to the appropriate kernel generation stations.

Cut Kernels

Kernels were produced using a commercial cutting machine (FMC Corporation, Model 3AR). Cutting depths were adjusted to produce kernels cut above the embryo (shallow cutting depth) and kernels cut midway through the embryo or at the glume line (normal cutting depth) (5). During normal plant operation a cutter of this type would have a low flowrate stream of water directed over the blades. This stream continuously cleans the cutter but combines with the kernel mass. The associated liquid waste is eluted from the kernel mass during washing or blanching. This stream was not used during the short duration process runs in this study. However, at the completion of a cutting test, the cutter was carefully cleaned with water which was collected and measured. A sample was drawn from this water for effluent characterization. Since this cutter cleaning effluent was considered to be a normal part of the wash effluent in the continuous use of this unit, it is so reported below.

Intact Kernels

Four methods were applied for the production of intact or unit kernels. Two of these methods were based on the cutting principle: separation of the corn kernel by impacting the tissue near the point of attachment to the cob with a sharp, rapidly moving object. Two other methods were applied which operated by applying forces to the top surface of the kernel and stressed the kernel so that separation would occur at the natural abscission layer.

The first alternative, a cutting method, used a conventional cutting machine set for its maximum or deepest cut. Cutter washing was conducted as above. Kernels produced by this method are referred to as intact-DC and the process is identified as the deep-cut process.

The second alternative, a cutting method, used a specially designed unit to cut at depths greater than attainable by the conventional cutting

machine and is shown in Figure 4. This unit or hole saw consisted of a cylinder having a diameter less than or equal to the diameter of the circle described by the locus of the kernel abscission layers. One end of this cylinder was machined to provide self-cleaning teeth. The entire cylinder was externally driven around its cylindrical axis by suitable mechanical means. To produce intact kernels, an ear of corn was forced endwise into the rotating teeth. The core of the ear passed through the cylinder and exited at its far end; whereas, the kernels and "sawdust" dropped into a receiving bin. Since corn ears with widely differing diameters were tested, several sawing elements with suitable diameters were provided.

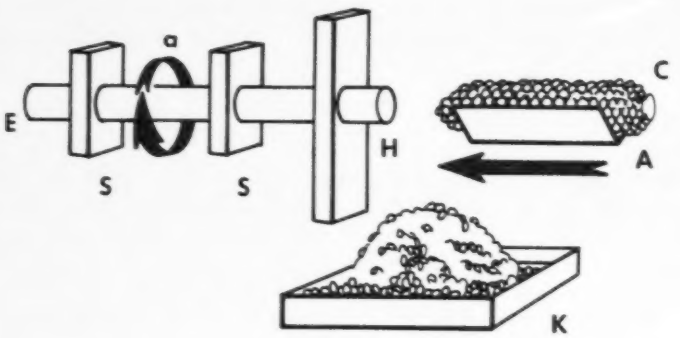


Figure 4. Schematic of "hole-saw" unit. Each ear of corn (C) is supported on a guide (A) and forced into the cylindrical cutter (H). This cutter tube is supported (S) and rotated (a) about its axis. Kernels are collected in a pan (K) and stripped cobs leave the cutter tube at its exit (E).

Kernels produced by this unit are designated intact-HS and the process is identified as the hole-saw process. The kernels and sawdust from the hole-saw process were separated by screening. Yields reported below are for freshly produced and screened kernels.

The third and fourth alternatives were each preceded by an ear disassembly step which was designed to gain access to the kernels with a minimal loss of yield to damaged kernels. This disassembly step was the longitudinal splitting of each ear and was accomplished by forcing a narrow wedge into each ear from one end through to the other end. The wedge dimensions, 19-mm wide on the flat side with a 7.6° taper, were chosen so so that the cob tissue only was affected during the splitting and kernels were not cut or damaged. To split accurately, the wedge was fitted with a 5-mm diameter, 20-cm long, center-mounted guide pin (see Figure 5). In operation, this pin was inserted into and through a 0.64-cm diameter

guide hole which had been drilled into the pithy core of each sweet corn ear from butt to tip. Next, the wedge-opposite end of the supported ear was restrained, and then pressure was applied to the wedge to force it into and through the ear of corn (Figure 6).

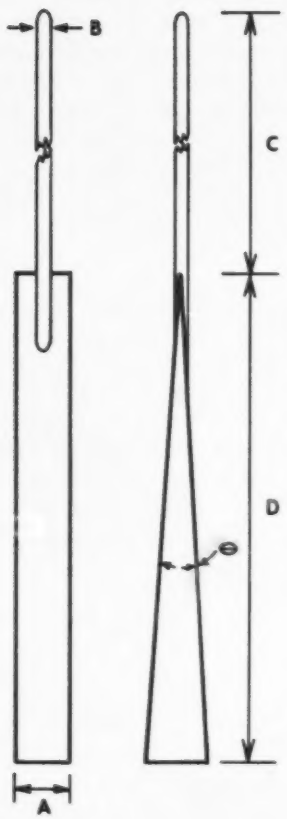


Figure 5. Front and side view of element used to longitudinally split ears of sweet corn. Dimensions shown are A, 19 mm; B, 5 mm; C, 200 mm; D, 19 mm; and θ, 7.6°.

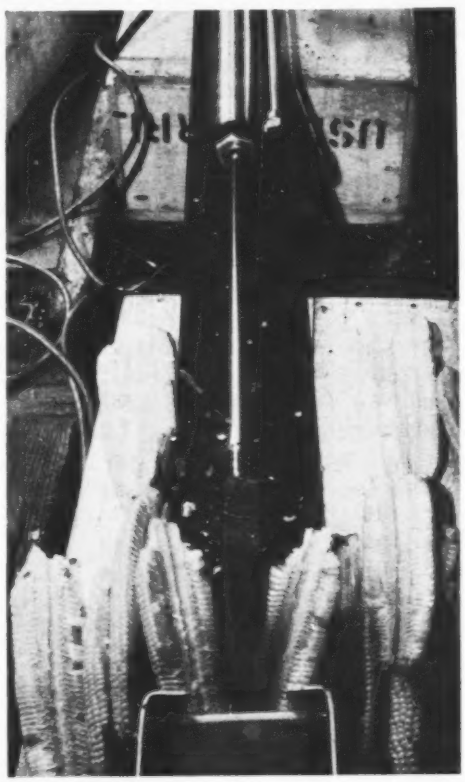


Figure 6. Apparatus used to split ears of corn.

Each of the third and fourth alternative methods produced intact kernels by pressing ear split sections against a moving, friction developing surface. Here, an ear section was oriented so that the moving surface in contact with the kernels was tangent to the ear radius, and kernels were removed a row at a time.

The friction surface of the third alternative was a custom molded, 5.1-cm wide, 45 to 50 durometer, silicone rubber belt (General Electric liquid molding compound type RTV-630 with 10% catalyst). The surface of the belt was molded with integral, 0.95-cm long, 0.32-cm diameter rubber projections, which were arranged in rows parallel to the axis of rotation. The center-to-center inter-projection spacing in each row and the center-to-center inter-row spacing was 0.48 cm. The projections in alternate rows were staggered. Rows were grouped in threes with a 1.27-cm center-to-center space between the projections of the closest rows of each group of three. This spacing was provided to allow indexing of the rows of kernels with the grouped rows of projections. This deeply textured belt was mounted on a 11.1-cm diameter, vertical wheel and driven at 60 rpm by a 370 watt (1/2 hp) motor.

Ears were positioned manually (Figure 7) at the 3 o'clock position of the clockwise rotating wheel and pressed against the textured surface. As each row of kernels was removed, the ear was rotated counterclockwise around its long axis in order to bring an undetached row of kernels into contact with the surface. Detached kernels were collected in a pan placed under the wheel. A 150° to 200°C air stream was directed across the contact surface of the wheel in order to evaporate corn juices and maintain friction with the kernels. The kernels produced by this method are referred to as intact-TS and the process is identified as the textured-surface process.

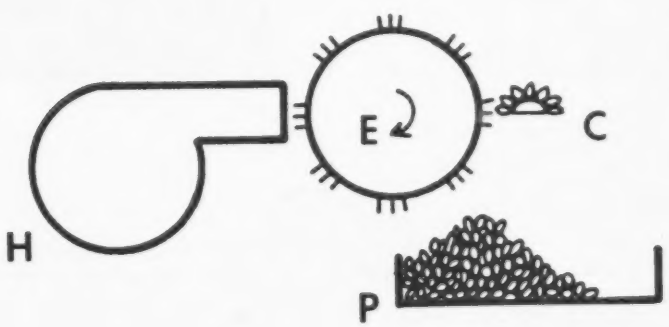


Figure 7. Schematic of textured-surface process for intact kernels. Shown are working wheel (E), air heater (H), sweet corn ear (C), and collecting pan (P).

The friction surface of the fourth alternative was a 10.8-cm wide, 3-mm thick, 58-durometer, food-grade neoprene belt. This belt was mounted on two 11.1-cm diameter wheels as shown in Figure 8. The working wheel (E) shown in the Figure 8 had a 0.64-cm thick overlying belt of 50-durometer silicon rubber. Two 0.15 gm/cm^3, closed cell, urethane foam "bumps" were attached to this belt 180° apart. These wedge-shaped bumps increased the working radius to 1.5 cm over a circumferential distance of 7.0 cm. The tapered bumps were designed to account for ear diameter differences of rigidly supported ears presented to the surface by a mechanical feeder. When ears were manually presented to the surface, the bumps served as an index guide (as did the grouped projections of the textured surface) and provided increased friction since they allowed for some conformation of the belt surface around the kernel surface. Figure 9 illustrates the presentation of a corn ear section to this device.

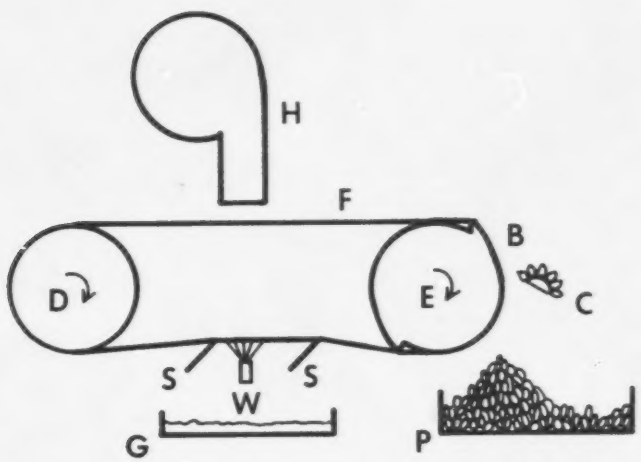


Figure 8. Schematic of smooth-surface process for intact kernels. Shown are drive wheel(D), working wheel (E), index bump (B), friction surface (F), scrapers (S), water spray (W), hot-air blower (H), and corn split (C).

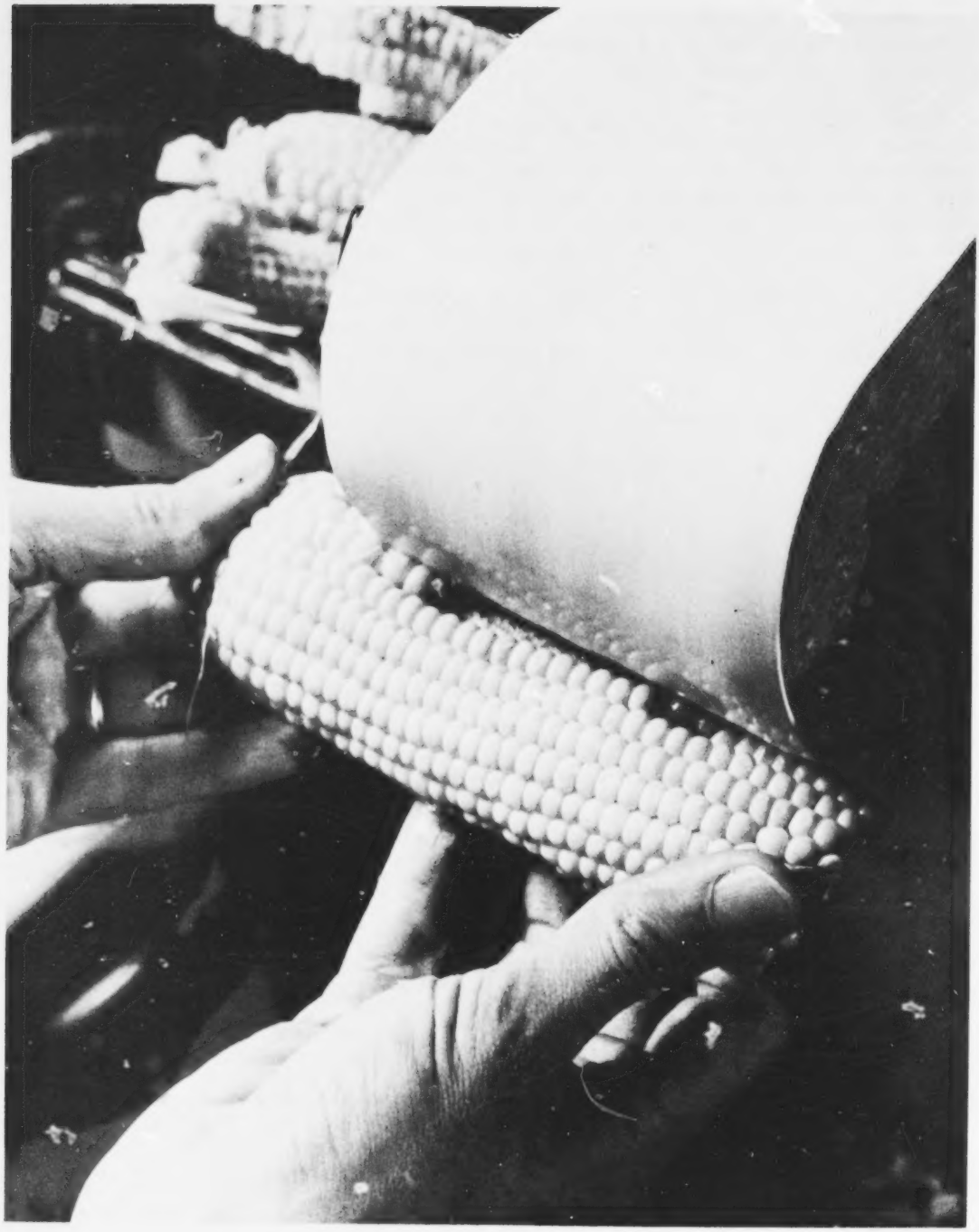


Figure 9. Smooth-surface frictional removal of sweet corn kernels.

Other features of this alternative are indicated in Figure 8 and were incorporated to insure a high friction coefficient between kernels and belt. For instance, scrapers were positioned against the belt to remove corn juices, silk, and kernel fragments. A low-volume water spray was directed against the belt between the scrapers to effect cleaning, and a hot air stream from a blower dried the belt.

Wash water collected during process runs was weighed and sampled and is included as a contributor in the total wash effluents described below.

Kernels produced by this method are referred to in the text as intact-SS and the process is identified as the smooth-surface process.

Post-Preparation Processing

Corn kernels produced by each method were washed in water using a pilot scale, shaker washer (A.B. McLauchlan Co., Inc.). Kernels entered this washer through a 11-mm square-opening, woven-wire screen to exclude oversize extraneous material and exited from the washer over a 6-mm square-opening, woven-wire screen to exclude undersize extraneous material. Water flowed into the washer over a weir at the feed end, flowed co-currently with the kernels, and exited from the washer through the undersize screen. In addition, water was applied through two rows of fan-spray jets located at the washer exit. The average ratio of water flow mass to kernel mass was 5.6 to 1. Waterflow was divided equally between the two rows of jets. The first row of jets encountered by the kernels was pitched to impart forward motion to the kernels to advance them out of the washing zone; whereas, the second bank encountered was a perpendicular curtain over the undersize screen and helped separate debris and kernel fragments from the desired kernels. Kernels leaving the washer were collected in a perforated basket and weighed.

All of the water used during washing was collected and sampled for analysis. During 1977 this water was then filtered through a 32-mesh screen to recover kernel embryos, silk, and undersize kernels which had not been removed at the exit screen.

In some cases (1976), a brine flotation in a NaCl solution was applied to eliminate excessive cob fragments.

Cleaned and floated kernels were blanched for 3.0 minutes on trays in a continuous steam blancher operating at 99°C. Tray loadings of 8.1 kg/m^2 were employed. Blancher effluent was collected during and for 10 to 15 minutes after blanching, and its volume measured and recorded. During 1976 blanched kernels were air cooled in forced air and then frozen on trays in a cross-flow, air-blast freezer operating at -29°C and at 3.6 mps. During 1977 blanched kernels were either frozen as above or canned. Canning was conducted the same day at the National Food Processors Association (National Canners Association)/Tech S Corporation. Canned corn was retorted in an agitated retort with a 5-rpm cooker speed (equivalent to 235 cans per minute). The initial temperature of the corn was 38° to 49°C and each lot

was processed for 20 minutes at 122°C and water cooled for 10 minutes. C-enamel, 303 x 406 cans used in this study were filled with 0.34 kg of corn and covered with a 4%-sucrose 2%-NaCl solution for a minimum 0.64-cm interior headspace.

MATERIAL BALANCES, SAMPLE ANALYSES, AND PHYSICAL TESTS

The mass of each sublot of corn was measured before husking and after each step indicated in Table 1. Weighed kernel samples were drawn at the process steps indicated. A 70-90 gm sample was drawn for total solids analysis (6) and only in 1976 a 130 to 200 gm sample was drawn for analysis of kernel characteristics. Material balances were corrected for sample weights, when appropriate. Liquid samples were drawn from the the cutter effluent, the belt effluent (1977), the kernel washing effluent, and the blancher condensate. All liquid and solid samples were stored at -29°C before analysis. Thawed liquid samples were analyzed in 1976 by the National Food Processors Association for TOC, COD, TS, SS, and BOD (8). Liquid samples collected in 1977 were analyzed at the Western Regional Research Center for TOC. Effluent data are reported below as units of COD per 100 units of product sweet corn (pph). Conversion to other indices can be made through use of factors described in Appendix 1.

TABLE 1. PROCESS FOR SWEET-CORN EXPERIMENTS

Step description	(1976) Weight recorded	(1977) Weight recorded	(1976) Kernel sample	Effluent sample
Harvest				
Transport				
Composite	X	X		
Husk	X			
Trim	X	X		
Generate Kernels (Four methods)	X	X	X	X
Clean (Two methods)	X	X	X	X
Steam blanch	X		X	X
Air Cool	X	X		
Freeze	X	X	X	

Subsamples of 70-100 g were drawn from stored bulk lots for analyses of Kjeldahl nitrogen (9), crude fiber (10), crude fat (11), and for amino acid composition on a Durrum Model D-500 Amino Acid Analyzer.

Belt Friction Measurement

Drag forces were measured by applying a horizontal force to a 2.5-cm diameter, 100 g, brass weight resting on a horizontal test surface. The horizontal force was applied and measured with a maximum reading spring gauge. Force was applied until the weight was set in motion. Data are reported as static coefficient of friction, η_s, which equals the horizontal force divided by the normal force.

The surface was tested after cleaning with a detergent and water solution, rinsing, and drying; after application of a continuous water film on the surface; and following application of a continuous film of freshly prepared corn juice. In addition, the corn juice film was tested repeatedly as it dried and finally when it had formed a hard, glassy crust. Each measurement was repeated 10-20 times.

Measurement of Optimum Position of Ear Relative to Successful Kernel Removal.

The belt device shown in Figures 8 and 9 was duplicated in a 2.5-cm wide version and provided with a variable height table and a variable position guide so that the split ears of corn presented to the working wheel could be accurately positioned. For this experiment, each split section was positioned as indicated in Figure 10 so that the point of contact of the friction element at its greatest radius ($\overline{AC}$) was identical with the intersection of the interkernel divider ($\overline{BC}$) and the arc based on the radius from the ear center to the kernel tip ($\overline{BE}$). For design purposes the ear was assumed at 20 rows, and the ear radius ($\overline{BE}$) at 2.54-cm. Up to 12 ears were tested at each of several point-of-contact angles from 27° to 63°.

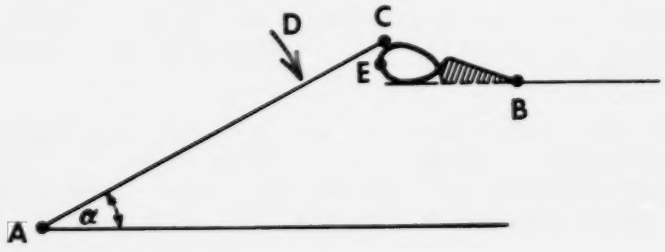


Figure 10. Cross section illustrating corn split section position with respect to frictional removal element. Shown are center of rotation of removal element (A), initial point of contact (C), center of ear section (B), direction of rotation (D), and point on kernel surface (E) farthest from the center (B).

Recovery on a per ear basis was measured by collecting and weighing kernels obtained at each position. Damage was measured by mixing 100 g of kernels produced at each position with 500 ml of water and stirring for 2.0 minutes. This mixture was separated on a 20 mesh screen , and the liquid bottled and stored at 0°C for subsequent thawing and TOC analysis. A control sample of 9 ears was manually presented to the wheel so as to obtain complete kernel removal with minimal damage, and these kernels were weighed and extracted as above. Results are reported relative to the manual experiment. Both Stylepak (20-22 rows) and Golden Jubilee (18-20 rows) were employed in the testing.

Sensory Evaluations

Frozen samples were prepared by cooking for 2 minutes in boiling water and draining. Canned samples were heated to boiling in their own liquid and drained. The drained corn was kept warm in a bottom-heated, covered dish during each of the panel sessions. Thirty to 40 g of each corn sample were placed in coded 1 oz paper cups and served in pairs to the panel. Relative acceptability of the freshly prepared and processed corn was estimated by hedonically rating the paired samples on a 9 to 1 like - dislike scale (12). Relative preference for cut or intact kernels was determined by paired preference test. The hedonic results were analyzed by the paired t-test and significance of the preference data was determined from tables (16). The panelists for the hedonic and preference tests were a random mixture of laboratory personnel about equally divided between male and female, and ranging in age from 24 to 59 years.

All sensory tests were conducted in a room containing individual booths maintained at a constant 24±1°C and 50% RH. Each booth was equipped with subdued lighting (7.5 watt green bulbs) to minimize appearance differences between the cut and intact kernels.

Measurement of Kernel Resistance to Abscission

Sweet corn ears were sampled from freshly harvested lots of corn or from corn which had been refrigerated at 1°C for no more than two days. Ears were husked, reselected for straight rows, and split longitudinally as described above.

During 1976, split sections were tested directly or subjected to a pre-test treatment. During 1977, split sections were tested after they were stripped of kernel rows except for a single row of kernels along the split-ear vertex with respect to its flat surface.

1976 Testing This test, indicated as 45 x 3, is illustrated in Figure 11. Each split ear tested was pressed manually against a probe so that three kernels were removed simultaneously and so that the angle between the applied stress and the kernel axis was 45°. The probe was attached firmly to a force transducer (Daytronic 152A-10T). The signal from the transducer was conditioned (Daytronic differential transformer #61) and automatically recorded. The probe surface was cushioned with a 5-mm layer of a 0.15-g/cm^3, closed cell, polyurethane foam.

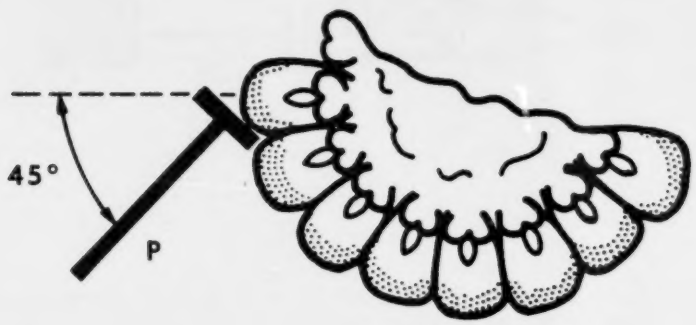


Figure 11. Cross section of a 45 x 3 kernel displacement test showing transducer probe, P.

The maximum force during kernel detachment was recorded and a mean computed for each ear. This mean did not include data from the row adjacent to the split surface since the force computed for this row was lower than for rows not adjacent to this surface.

Thermal treatments were applied to ear split sections. The detachment force then was measured and compared to the detachment force measured on the corresponding untreated half. Thermal treatments included exposure to steam and full immersion in boiling water.

1977 Testing This test, indicated as 90 x 1 or 90 x 2 was applied to a single row of kernels along the ear vertex as shown in Figure 12. Split sections were mounted in a holder to increase rigidity of the piece and the holder was attached firmly to the force transducer platform. The platform was designed so that the ear flat surface was parallel to and its long axis was perpendicular to the direction of measurement. The transducer mounting platform was adjusted to position kernel(s) in front of a slowly moving (77.3 cm/min) displacement hammer so that the face of the hammer contacted the entire side of each kernel at and above the glume line and displaced each kernel in a direction parallel to and towards the transducer and perpendicular to the axes of ear and kernels. Furthermore, displacement hammer, kernel, and transducer were in alignment.

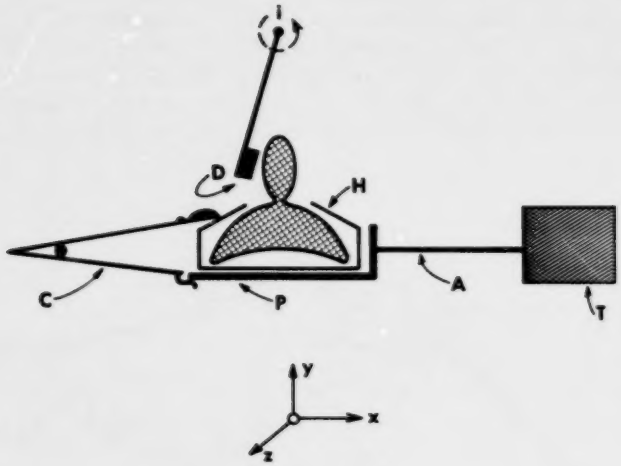


Figure 12. Cross section of a 90 x 1 or 90 x 2 kernel displacement test showing kernels (K), holder (H), transducer platform (P), transducer (T), and displacement hammer (DH).

The row on one split half of each ear was tested one kernel at a time (90 x 1) and the row on the corresponding split was tested two kernels at a time (90 x 2).

The maximum force during displacement of kernel(s) was recorded and separate ear averages were computed for the single kernel displacement and for the double kernel displacement. The ear averages excluded the four kernels at the tip and at the butt to minimize end effects due to kernel immaturity (tip and butt) and kernel distortion (butt end).

A force, F_A, related to the butt or kernel abscission resistance to detachment and a force, F_F, related to frictional resistance between the displaced kernel(s) and the adjacent undetached kernel were computed from

$$F_A = F_{90 \times 2} - F_{90 \times 1}$$

$$F_F = 2F_{90 \times 1} - F_{90 \times 2} .$$

$F_{90 \times 1}$ is the average force for single kernel displacement (one abscission and one friction component), and $F_{90 \times 2}$ is the average force for a two-kernel displacement (two abscission and one frictional components).

Kernels separated during the 45 x 3 test or during the preparation for 90 x 1 or 90 x 2 testing were collected, frozen to 0°C, and later thawed for measurement of moisture content and kernel dimensions.

SECTION 5

RESULTS AND DISCUSSION

The reasons for the substitution of intact kernels for cut kernels were suggested in earlier work (5). This work elaborates on that initial effort to determine the desirability of the substitution by using raw materials and processing methods comparable to those currently in use or which could be put in use in the processing industry and by using these materials and processes on a scale which can more accurately model a full-scale operation. Data and results for each of several methods give waste-producing characteristics, yield characteristics and the quality of the kernel mixture. At the same time, this work initiates efforts to define the physical mechanisms by which intact kernels may be produced.

WASTE GENERATION CHARACTERISTICS

Estimation of the Waste Reduction Potential for Intact Kernels

In order to estimate the waste reduction potential, wasteloads for cut kernels were compared to estimates of practical and ideal minimum waste loads for intact kernels. The estimate of the practical minimum waste for intact kernels was made by correlating measured wasteloads from washing or blanching with the percentage of washed or blanched kernels which had cut surfaces or broken pericarp and then extrapolating to 0% cut or broken kernels. The value of this intercept was taken as the practical minimum. The wash wasteload versus broken or cut kernel correlation is shown in Figure 13 and the value of the practical minimum was 0.37-pph COD. The practical minimum for blanching was 0.067-pph COD.

An ideal minimum wasteload, which corresponds to the waste strength of carefully detached kernels, and a second practical minimum were estimated in a separate experiment. In this experiment, the wash wasteload from kernels that were mechanically detached from ear splits by the smooth-surface process was compared to the wash wasteload from kernels that were manually detached from the corresponding ear halves. A practical wash wasteload of 0.31-pph COD was obtained for the mechanically detached kernels and compared favorably to the value of 0.37-pph COD above. An ideal minimum wash wasteload of 0.13-pph COD was obtained for the manually detached kernels.

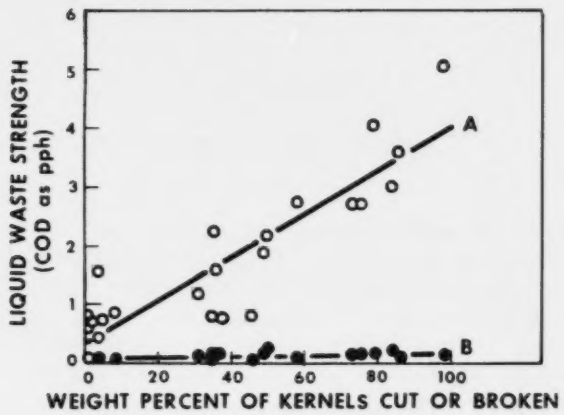


Figure 13. Liquid waste strength of cut and intact-kernel samples for washing A and blanching B.

Cut-kernel waste strengths are shown in Figure 14 for washing freshly prepared kernels. The fitted curve in this figure was interpreted as constant for yields above 42% since this yield corresponds to the theoretical maximum yield for cut kernels. Furthermore, higher yields represent inclusion of inedible "cobby" matter which does not contribute significantly to the waste. The decline of specific waste loading with increasing yield for the recovery range up to 42% was expected since the loading is proportional to cut surface area: as the kernel is cut more deeply, the ratio of cut surface to kernel mass decreases.

An estimate of the waste reduction potential for washing intact kernels then was obtained from the practical and ideal minima for intact kernels and from cut-kernel waste strengths determined for approximate industrial conditions. Estimated "practical" waste reductions range from 85.2% for a 40% recovery to 94% at a 33% recovery. Estimated ideal reductions are 95% and 98% for the same range. If industrial recoveries of 35% are used, the reductions predicted are 91% and 97% for the practical and ideal cases, respectively.

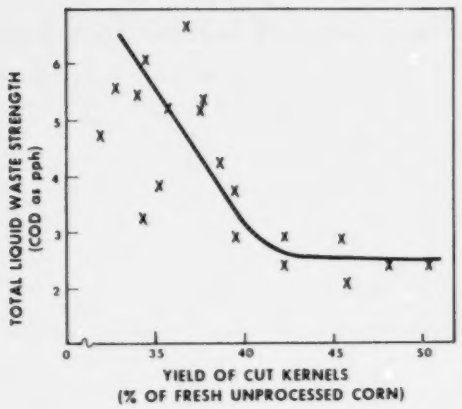


Figure 14. Waste strength for cut-kernel samples.

Waste From Alternative Kernel Producing Methods

The result of effluent measurements for kernels from the five kernel producing methods are shown in Table 2. Based on these results, the method generating the least waste was either the textured-surface or smooth-surface process. Closely following was the hole-saw process; but its waste load per mass of product is subject to revision to a higher value, since not all of the kernel mass of frozen product would be suitable for consumption. This revision also applied to the deep-cut samples. Furthermore, the waste from intact kernels produced by the deep-cut process more closely resembled that from conventionally cut corn as would be expected on the basis of the large percentage of cut kernels in the intact-DC mixture.

Washing sweet corn kernels of any type resulted in a wasteload 10 to 20 times that produced by blanching. This observation reflects the order in which the unit operations were performed, since the greatest leaching would be expected to result from the first contact of kernels and water.

The portion of the wash wasteload attributed to the smooth-surface belt washer is reported in Table 3. This contribution amounts to 14% to 17% of the total from the belt washer and kernel washer.

The wasteloading identified with variety in Table 3 increases in the order Golden Happiness to Golden Jubilee to Stylepak for both cut and intact samples. However, the percentage differences for washing intact kernels of different variety, and especially the percentage differences associated with the belt washer are larger than for the cut comparisons. Varietal susceptibility to pericarp rupture during frictional kernel detachment and the relative ease of kernel detachment may be factors causing these differences.

TABLE 2. WASHER AND BLANCHER LIQUID EFFLUENT STRENGTHS

(Basis: 100 Mass Units of Frozen Product or pph)

Kernel type[a]	Gross recovery of fresh kernels percent	Wash COD pph	Wash COD SD	Blanch COD pph	Blanch COD SD
Cut (1976)	38.	3.5	0.9	0.15	0.04
Cut (1977)	34.	4.7	1.0	0.25	0.10
Intact-DC	46.	2.1	0.4	0.16	0.04
Intact-HS[b]	46.	0.9	0.2	0.08	0.04
Intact-TS	41.	0.6	0.5	0.06	0.04
Intact-SS[c]	44.	0.6	0.2	0.04	0.01

(a) All variety averages
(b) Kernels screened before washing and blanching
(c) Wash waste includes contribution from belt washer, See Table 3.

TABLE 3. CONTRIBUTIONS TO EFFLUENT STRENGTH

Variety	Kernel type	Belt washer effluent COD pph	Belt washer effluent SD	Kernel washer effluent COD pph	Kernel washer effluent SD
Golden Jubilee	Intact SS	0.10	0.14	0.50	0.02
Stylepak	Intact SS	0.13	0.10	0.70	0.10
Golden Happiness	Intact SS	0.05	0.01	0.31	0.01
Golden Jubilee	Cut	--	--	5.29	0.23
Stylepak	Cut	--	--	5.60	0.18
Golden Happiness	Cut	--	--	3.92	0.58

Washing also was found to be a substantial source of filterable solid waste. Suspended solids were separated from the kernel mass at the washer feed screen as oversize solids and from the wash effluent as undersize solids. As shown in Table 4, the oversize solids from washing cut or intact kernels and the undersize solids from washing intact kernels were small percentages of the unscreened corn kernels; however, the undersize solids from washing cut kernels were a considerable fraction of the total.

TABLE 4. SUSPENDED SOLIDS COLLECTED DURING WASHING OF CUT AND INTACT-SS KERNELS[a]

Kernel type	Oversize solids	Undersize solids
	% of feed	% of feed
Cut (1977)	0.7	6.6
Intact (1977)	0.8	0.8

[a]Calculation based on moisture-free solids in feed, oversize, and undersize product streams.

The undersize solids from washing cut kernels included embryos; pieces of pericarp; very shallowly cut kernels, which would not be considered saleable; glumes; cob fragments; insects; and immature cut kernels originating at the tip of each ear. Undersize solids from washing intact kernels included pericarp fragments and cob fragments. Oversize solids originating from cut kernel samples included sections of cob broken from the ear during cutting and husk leaves. Oversize solids from intact kernel samples included strips of kernel rows attached to thin strips of cob tissue and, especially in the case of Golden Happiness, groups of detached kernels which were adhering to each other.

Waste Loading and Machine Variables (Smooth-Surface Process)

Waste loading, which results largely from kernel damage, was correlated to the relative position of the ear split section and the moving friction surface. This is shown in Figure 15 where TOC is used to index kernel damage in kernel samples produced from rigidly supported ears of sweet corn. At angles less than 30° so few kernels were removed that effluent measurements were not made. Damage increased as the angle increased above 30° because of the greater tendency to crush kernels before detachment and to crush kernels against the cob after detachment.

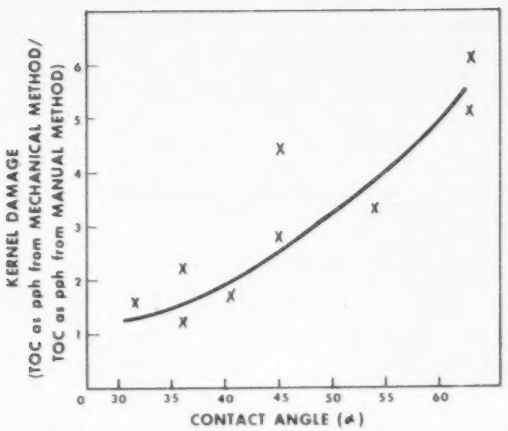


Figure 15. Kernel damage resulting from contact with frictional element. (Refer to Figure 10).

YIELD CHARACTERISTICS

Estimation of the Yield Increase Potential for Intact Kernels

An estimate of the practical potential yield increase for intact kernels was made by comparing cut-kernel yields to intact-kernel yields measured during the 1976 and 1977 processing tests. This comparison is shown in Figure 16 for freshly produced kernels, in Figure 17 for washed kernels and in Figure 18 for frozen kernels. In each figure, the intact-kernel yield increase is plotted against the corresponding absolute cut-kernel yield. Then, for example, if a fresh cutting yield of 35.5% was obtained, a practical increase of 20% would be expected for intact kernels or a net 42.6% yield of intact kernels. In the cutting range of 33% to 40%, which was utilized in the waste potential comparison above, the practical increase varies from 26% to 5%. Results shown for washing and for freezing indicate that the relative yield advantage for intact kernels improves at each successive processing step. This improvement occurs because shrinkage or losses due to both leaching and screening are smaller for intact than for cut kernels at every step where losses can occur.

The results of Figures 16 to 18 can also be used to estimate cutting yields at which there is no yield benefit for intact processes (the cutting yield for 0% ordinate). This equal yield point occurs at 42% yield for fresh and washed comparisons and at 38% yield in the frozen comparison. It should be noted, however, that cutting yields in the range above 40% for fresh kernels are not commonly sought because of the unavoidable inclusion of undesirable cobby tissue.

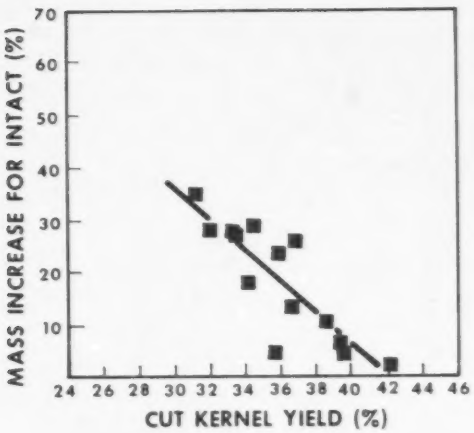


Figure 16. Yield increase of intact over cut kernels for freshly prepared kernels.

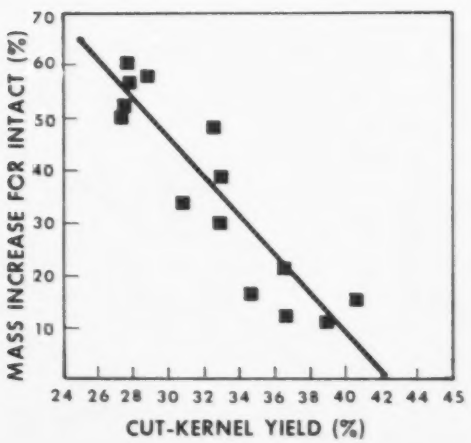


Figure 17. Yield increase of intact over cut kernels for washed kernels.

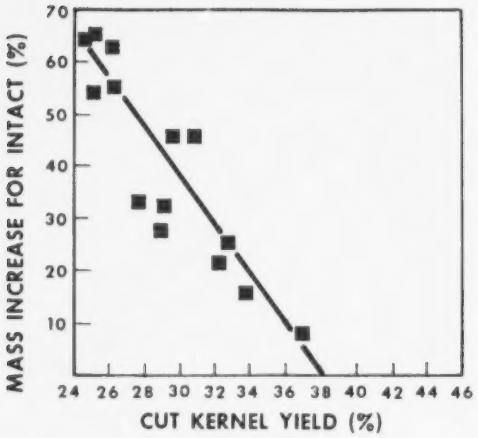


Figure 18. Yield increase of intact over cut kernels for frozen kernels.

An experimental estimate of the maximum available edible material on the cob was made by adding the mass recovered mechanically by either of the intact frictional processes to the mass recovered by scraping the remaining kernels from the ears. The result of these experiments is shown in Figure 19 for Jubilee, Stylepak, and Golden Happiness. Ideal yields of 50% at 70% moisture or 44% at 73% moisture are indicated by the fitted curve.

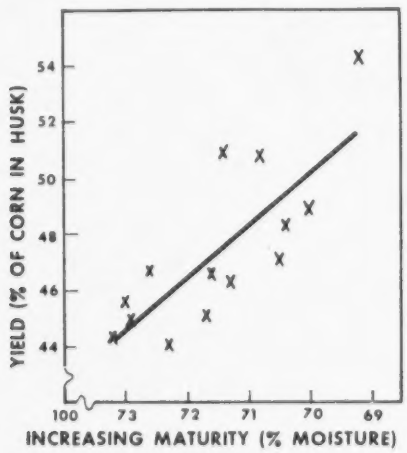


Figure 19. Ideal yield of intact sweet corn.

One factor which affects the degree of success in approaching ideal or complete removal is the variety of the sweet corn tested. As shown in Table 5, the order of decreasing effectiveness of kernel removal is: Golden Happiness, Stylepak, and Golden Jubilee. This order corresponds to the order of decreasing strength of kernel attachment.

Another factor contributing to the success with which kernels are removed is the position on the cob from which the kernels are detached. Immature kernels at the tip and large, tightly-packed kernels at the shank or butt were not easily removed and were frequently broken during or before detachment. Qualitative observations of the extent of this effect in each variety agree with the ranking of Table 5. The extent of the effect was quantified during one test (Table 6) by cutting the processed splits into approximate length fractions of 1/5 near the tip, 3/5 in the center and 1/5 at the butt. These results show that 79% of the unrecovered kernels are located in the end fractions.

TABLE 5. APPROACH TO COMPLETE OR IDEAL KERNEL REMOVAL BY SMOOTH-SURFACE AND TEXTURED-SURFACE PROCESSES

	Ratio of actual to ideal recovery[a]		Average ideal recovery[a]	
Variety	%	SD	%	SD
Golden Happiness	94.5	2.3	48.5	3.9
Golden Jubilee	89.8	1.3	47.2	1.6
Stylepak	92.3	3.3	46.4	2.5

[a] Analysis of variance for actual recovery versus variety data yields F of 4.76, which is significant at 3% level; while ideal recovery versus variety yields F of 0.689, which is significant at 48% level.

TABLE 6. EAR LOCATION OF KERNELS NOT DETACHED BY FRICTIONAL TECHNIQUE (STYLEPAK)

Position on ear	Approximate linear fraction	Weight fraction of cob	Weight fraction of undetached kernels
Tip	1/5	0.19	0.31
Midsection	3/5	0.52	0.21
Shank or butt	1/5	0.29	0.48

Yield From Alternative Processing Methods

Gross yields, which are yields which do not account for the quality of the kernel mixture produced, were measured at each step in the process sequence and are reported in Table 7. Data are shown for cut kernels and for the three alternative methods tested during 1976. These tests compare data for tests in which all four processes were applied to a given harvest of corn. Every alternative process for intact kernels produced more gross yield at each step than the conventional cut process. Furthermore, the alternative processes may be ranked in order of increasing gross yield as textured surface, deep cut, and hole saw. These data also illustrate the greater resistance to losses by the intact-kernel processes.

These gross-yield data, however, are subject to interpretation since the kernel mass produced by each method contains various amounts of "defects" which detract from the uniformity and desireability of the final product. An indication of these differences is shown in Tables 8 and 9 for freshly prepared and frozen kernels.

Clearly, the textured-surface process developed a kernel mass having the most uniform character with the inclusion of the least amount of unobjectional matter (kernels with attached cob, smashed kernels, and cob fragments).

Moreover, if it is assumed that a clean separation can be made of the desired intact, or intact plus cut kernels, from the undesired extraneous matter; then potential, ideal, or net yield estimates can be made by correcting the gross yields in Table 7 by the kernel analyses summarized in Table 9. This correction changes the order of increasing yield to hole saw, deep cut, and textured surface.

The yield of intact-TS and intact-SS kernels is shown in Table 10. The freshly produced kernel yields for each process are approximately equal, even though the weight of trimmed ears was somewhat greater for the smooth-surface process. This difference was due principally to differences in

husking procedure. Ears supplied to the textured-surface process were mechanically husked and trimmed at the butt end and later trimmed at the tip end. Ears for the smooth-surface process were manually husked and trimmed. However, the difference in trimmed weights probably does not affect the kernel yield since all of the increase in trimmed weight for the textured-surface process may be accounted for by inclusion of tip and butt ear mass from which kernels were not easily recoverable.

TABLE 7. MASS RECOVERY[a] OF SWEET CORN AFTER EACH PROCESS STEP

Process step	Cut		Intact-DC		Intact-HS		Intact-TS	
	%	SD	%	SD	%	SD	%	SD
Husked ears	65.3	(2.6)	66.5	(2.3)	66.2	(2.1)	66.3	(0.7)
Trimmed ears	63.3	(2.1)	63.8	(2.0)	63.7	(2.5)	63.5	(0.6)
Detached kernels	38.1	(3.1)	46.3	(3.0)	46.4	(3.3)	40.9	(2.3)
Washed kernels	36.3	(3.8)	47.0	(3.5)	49.9	(4.6)	43.2	(2.6)
Blanched kernels	35.1	(3.8)	44.2	(2.9)	46.8	(5.3)	42.8	(2.5)
Cooled kernels	33.1	(3.6)	41.6	(2.9)	44.0	(5.3)	40.4	(2.1)
Frozen kernels (Gross)	32.0	(3.8)	39.6	(2.8)	42.8	(5.2)	38.8	(1.9)
Frozen kernels (Net)	31.0	(3.8)	34.9	(4.1)	34.0	(4.0)	37.7	(2.4)

[a] Basis 100 units of corn in husk at 71.8% moisture SD 1.3%.

TABLE 8. MEAN KERNEL WEIGHT DISTRIBUTIONS FOR FRESHLY PREPARED SAMPLES

Kernel mixture	Cut kernels %	Intact kernels %	Intact kernels with attached cob %	Smashed kernels %	Cob fragments %
Cut	80	12	0	3	6
Intact-DC	41	37	13[b]	4	4
Intact-HS[a]	22	52	23[c]	1	2
Intact-TS	0	95	3[d]	1	1

(a) Screened.
(b) 100% of entry due to attached cupule.
(c) 90% of entry due to attached cupule, remainder of entry due to attached rachilla (16).
(d) 54% of entry due to attached cupule, remainder to attached rachilla.

TABLE 9. MEAN FROZEN[a] KERNEL WEIGHT DISTRIBUTIONS

Kernel mixture	Cut kernels %	Intact kernels %	Intact kernels with attached cob %	Smashed kernels %	Cob fragments %
Cut	80	12	0	2	3
Intact-DC	38	41	15	2	4
Intact-HS	25	51	21	1	2
Intact-TS	1	95	2	1	1

[a]Actually measured on samples immediately after washing. No changes in distribution occurred between working and freezing steps.

TABLE 10. INTACT KERNEL YIELD COMPARISON FOR TEXTURED AND SMOOTH PROCESSES

Process step	Textured surface yield		Smooth surface yield	
	%	SD	%	SD
Harvest	100	1	100	2
Husk & Trim	63.8[a]	2.1	68.3[b]	2.6
Kernels	43.0	4.1	44.1	1.8

(a)Mechanical butting husker.
(b)Manual husk and light trim.

Yield Adjustment by Defect Removal (Density Separation)

One method for achieving the separation of desireable from undesireable intact kernels is by exploiting density differences. Summary data for density flotation in NaCl solutions are shown in Figure 20. The absolute position of these data along the abscissa was set by the results of flotation applied to kernels produced in the yield/effluent experiments

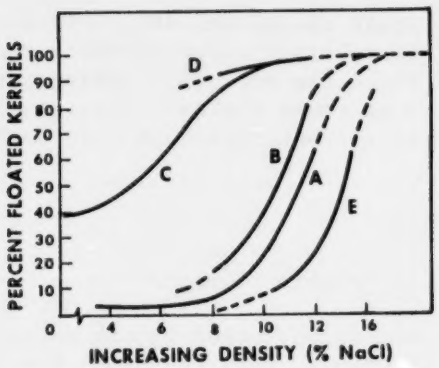


Figure 20. Density flotation of sweet corn. Types are intact kernels (A), intact kernels with attached rachilla (B), intact kernels with attached cupule (C), cob fragments (D), and smashed kernels (E).

described above. The relative position of each curve in a family of curves, as shown in the figure, was unchanged by variety, maturity, and temperature. The curves describe a density decrease from the cut form to the intact form, to intact forms with adhering rachilla, to intact forms with rachilla and cupule. The absolute kernel density, hence, the positions of the curve family, was found in preliminary tests to be sensitive to kernel temperature, maturity, and variety so that the entire family of curves would shift along the abscissa for each different condition.

The kernel density differences were not great, therefore, the removal of one component of the mixture will necessarily be associated with partial removal of other components. The predicted approximate effect of a density flotation separation applied to hole-saw mixture to reduce kernels with cupule and rachilla adhering is summarized in Table 11. Using this table, the quality of a mixture equivalent to that produced initially by the textured-surface process could be achieved by flotation of the hole-saw kernels, but there would be an associated loss of more than 20% of the desired kernels.

TABLE 11. PREDICTED LOSSES OF INTACT KERNELS FROM INTACT-HS KERNEL MIXTURES BY FLOTATION IN NaCl SOLUTIONS

Solution concentration weight percent	Desired kernels with rachilla or rachilla and glume attached weight percent	Associated loss of intact kernels weight percent
10	4.7	16
10.5	3.1	22
11.0	1.7	44

This flotation loss would reduce the net yield from the hole-saw process, and it would result in a larger value of waste per hundred pounds of useable kernels produced since the effluent loading reported earlier for hole-saw kernels was based on gross yields. The result of lower yield and increased waste reduces the attractiveness of this technique relative to the friction techniques.

Yield and Machine Variables

Kernel Position Relative to Friction Surface—

Yield of intact kernels was affected by the relative position of the kernel and the friction developing surface during the kernel detachment event. Yield, which is expressed here as the ratio of the mass of kernels removed to the mass of kernels available in a given row, is shown in Figure 21 for various positions of the ear and detachment surface. This figure indicated the ineffectiveness of small and large angles and suggested an optimum angle between 36% and 54%. Since the waste increases with increasing contact angle, an angle at the lower end of this range would be desirable.

Different types of surfaces likely will have different levels of sensitivity to position so that the conclusions reached in this section apply only to the smooth-surface process.

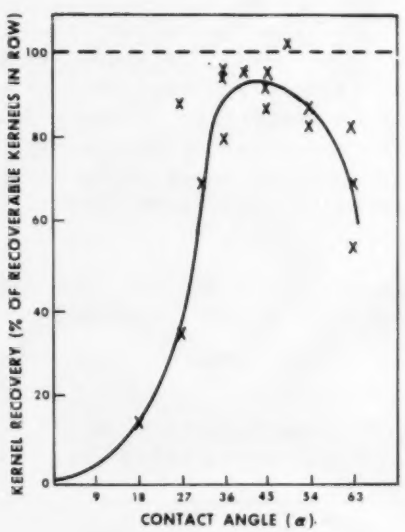


Figure 21. The role of kernel position relative to friction surface in successful kernel removal. Refer to Figure 10.

Quality of Friction Surface--

The success of the techniques for kernel detachment which rely on friction between the detaching element and the kernel surface depends on maintaining a high coefficient of friction between the contact surfaces. Friction is reduced if the juice of ruptured kernels coats either surface.

The magnitude of this effect in static testing is shown in Table 12 for the neoprene belt of the smooth-surface process. The clean and dry surface provides the greatest friction, but is closely approximated by a surface coated with a film of partially dried juice. In auxiliary tests, mass production rates for partially dry surfaces and for clean, dry surfaces were indistinguishable. The presence of either wet corn juice or fully dried juice reduced the maximum friction by 88%.

TABLE 12. STATIC COEFFICIENT OF FRICTION (η_s) FOR CLEAN AND CONTAMINATED NEOPRENE SURFACES

Surface Condition	η_s	SD
Clean and dry	3.3	0.4
Water film	1.3	0.1
Fresh corn-juice film	0.4	0.1
Partially dry corn-juice film	2.6	0.7
Fully dry corn-juice film	0.4	0.1

The textured surface also benefitted from the drying of the surface. When the surface was kept dry, flexure of the studded surface during kernel detachment fractured the embrittled juice film and broke it away from the surface. As an example of the effect, a 55% kernel recovery (husked ear basis) was achieved using a wet, unheated textured surface. However, this recovery was increased to 72% (husked ear basis) when the ear sections were reprocessed on a dry, heated textured surface. It was not necessary to continuously wash and dry the textured surface, since drying, the associated embrittlement of the juice film, and the flexure of the surface resulted in the removal of this slippery, dry film.

KERNEL QUALITY CHARACTERISTICS

The substitution of intact kernels for cut kernels is highly desireable from the standpoint of waste reduction and yield improvement. However, the desireability of this substitution also depends on acceptable quality attributes such as visual appearance, flavor, and texture. Intact kernels are visually distinguishable from cut kernels. Furthermore, since the intact kernel includes the kernel germ, whereas the cut kernel excludes all or part of the germ, sensory response to each kernel type should also be different.

Visual Evaluation of Sweet Corn Samples

Visual differences between samples of cut and intact kernels are usually clearly evident. This can be seen in Figure 22 which illustrates samples of corn freshly prepared by cutting and by the smooth-surface process. Subsamples of frozen-and-thawed, cut and intact sweet corn corresponding to the samples utilized in the 1976 sensory evaluation described below are shown in Figure 23, 24, and 25. Corn in each cut/intact comparison came from the same planting, harvesting, and processing day.

Figure 22. Freshly prepared, unwashed samples of cut and intact kernels

Figure 23. Frozen and thawed samples of cut and intact sweet corn (Var. Stylepak)

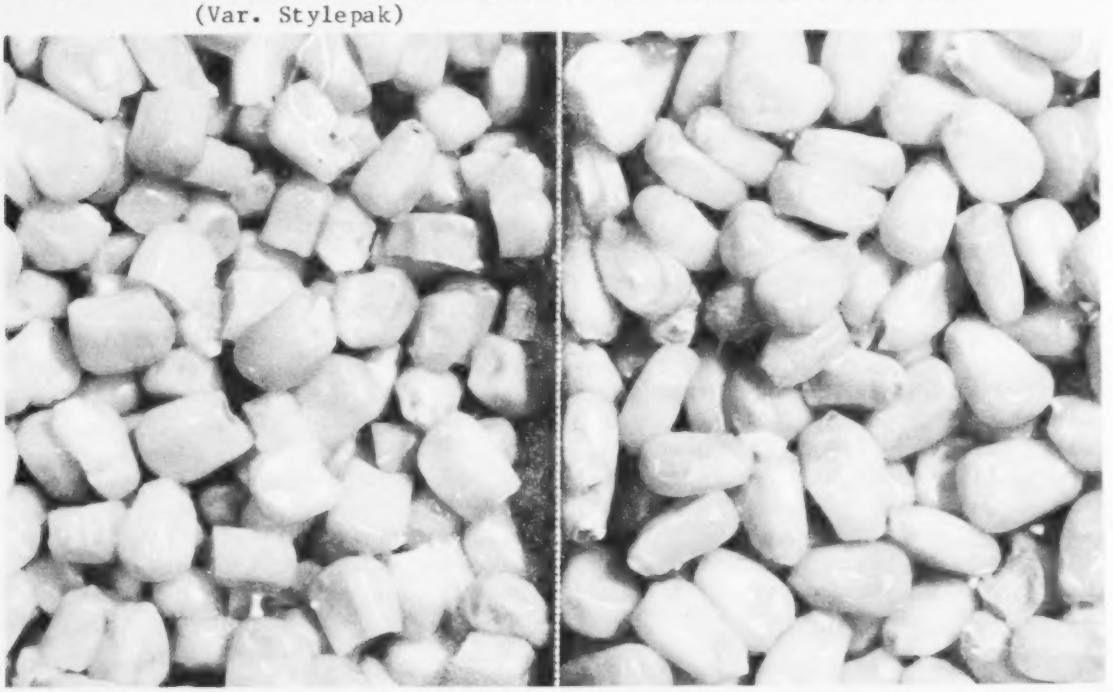


Figure 24. Frozen and thawed samples of cut and intact sweet corn (Var. Golden Happiness)

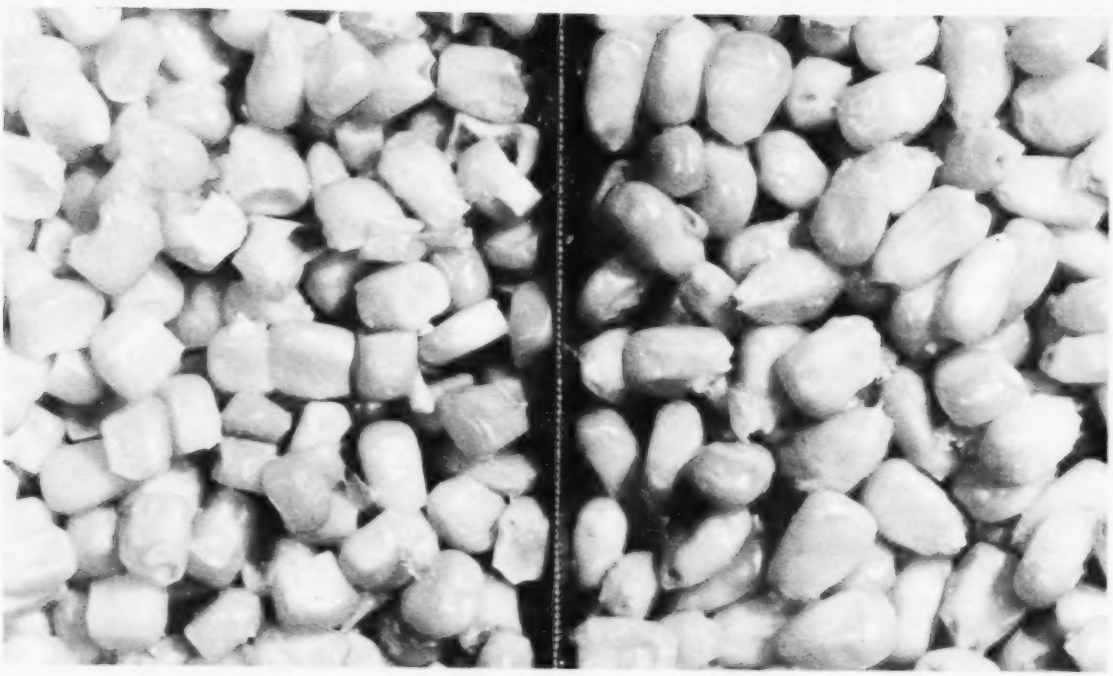


Figure 25. Frozen and thawed samples of cut and intact sweet corn (Var. Golden Jubilee).

No formal attempt was made to compare the visual acceptability of the two kernel types. This kind of evaluation would not have great meaning since it depends strongly on the past experience of the observer. However, visual differences were quantified within the group of kernels identified as intact kernels. A classification of kernel structural details was made to assess varietal differences and the effects of washing on altering these differences. The results are shown in Table 13 and Table 14 for intact kernels only. Identified here were glume "wings" or glume tissues which surround the lower third of the kernel (these are absent in Golden Happiness, a glume-free or vestigial glume variety); base glumes, or very short glumes which surround the base of individual kernels; and rachilla tissue, the woody conducting tissue which connects to the kernel at the abscission zone (17). Of these tissues, the glumes affect the visual appearance somewhat, whereas the rachilla affects both the visual appearance and the texture of corn. In the opinion of the authors, the glume-free, rachilla-free kernel was the most attractive and the kernel with rachilla tissue was the least attractive. Washing tends to improve the kernel appearance by increasing the proportion of the sample described as glume free.

TABLE 13. MEAN INCIDENCE OF GLUME TISSUES IN FRESHLY PREPARED INTACT-TS KERNEL SAMPLES

Variety	Kernel Characteristics[a]							
	Glume-free		Glume "wings"		Glumes at base		Rachilla attached	
	%	SD	%	SD	%	SD	%	SD
Golden Jubilee	3	0.5	7	7	88	3	2	0.5
Stylepak	16	10	1	2	82	8	1	1
Golden Happiness	69	15	0	0	30	14	1	1

[a]Mass percentage based on intact kernels only.

TABLE 14. ABSOLUTE CHANGE IN DISTRIBUTION FROM WASHING INTACT KERNELS

Variety	Glume-free	Glume "wings"	Glumes at base	Rachilla attached
	(Absolute change in mass percentage units)			
Golden Jubilee	+3	-3	0	0
Stylepak	+13	-1	-12	0
Golden Happiness	+5	0	-6	+1

Visual appearance differences related to the presence or absence of glumes can be seen in Figure 23 through 25. Also Figure 26 illustrates differences in individual kernels and cobs for the principal varieties studied. In this figure the Stylepak sample indicates a kernel with glume wings (7 o'clock position), the Golden Happiness with neither side nor base glumes, and the remaining kernels show glumes at the base.

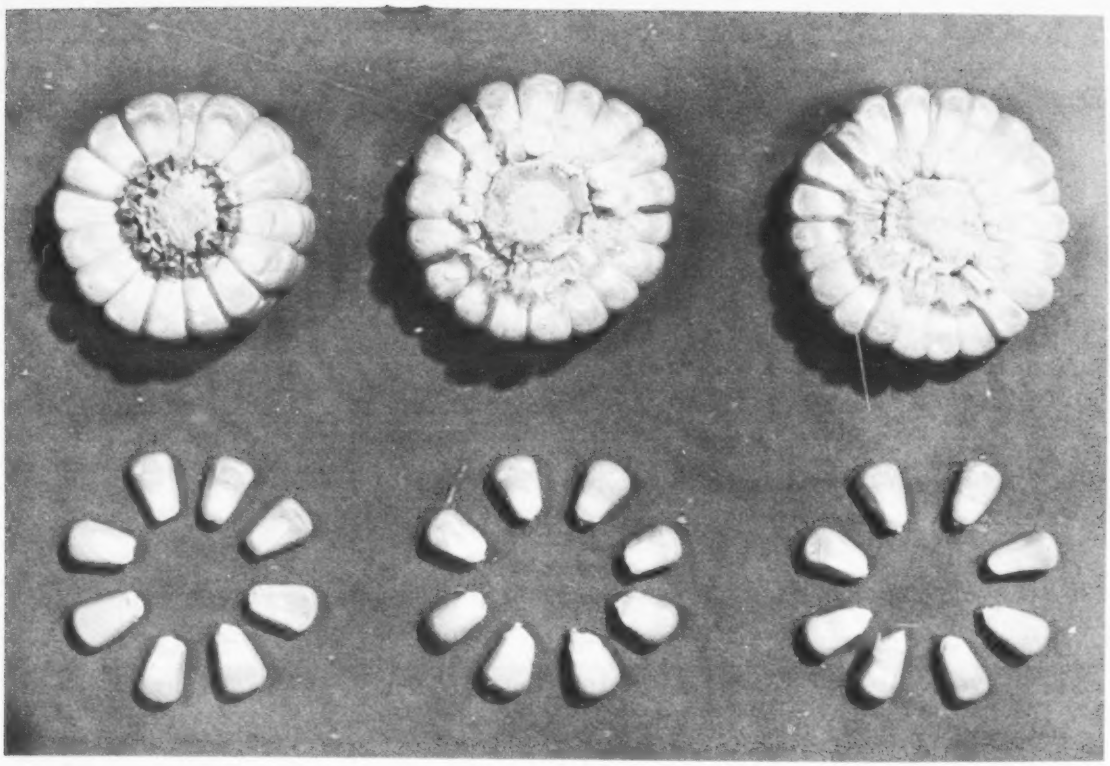
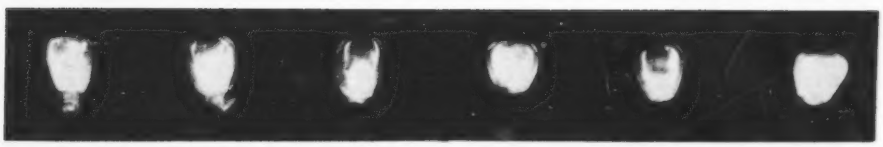


Figure 26. Corn cross sections and individual kernels of (l to r) Golden Happiness, Golden Jubilee and Stylepak.

In the grading of sweet corn for commercial "cut" or "whole kernel" packs, one factor which reduces the overall score for the product is the presence of pulled kernels. Pulled kernels lack a cut surface (i.e. an intact kernel) and their presence detracts from the sample uniformity. Reference to the corrected official interpretive guide of the USDA, Production and Marketing Administration and Inspection Division (Figure 27) indicated that not all intact kernels are classifiable as pulled kernels and that most kernels produced by the intact processes would not receive this designation if graded according to the cut kernel standards. By and large, however, these standards are probably inappropriate for intact kernel samples.



1. 2. 3. 4. 5. 6.

Figure 27. Adaptation of USDA interpretive guide illustrating pulled kernels and cut kernels in canned and frozen corn. Kernels captioned 1 and 2 are scorable as pulled kernels; whereas, kernels 3 to 6 are not scorable as pulled kernels. When the adhering cob material is very hard and affects the appearance and eating quality, it is considered as a pulled kernel (13).

Sensory Evaluation of Sweet Corn Samples

The result of sensory evaluation of sweet corn frozen in 1977 is shown in Table 15. In each case higher hedonic scores were obtained for intact samples than for the control cut comparisons (a value of 7 indicates the taste tester liked the sample very much; whereas, 9 indicates like extremely, 5 neither like nor dislike, and 1 dislike extremely). Statistical evaluation by the T-test supports the significance of these differences.

Data for hedonic ratings applied to frozen and canned samples prepared during 1977 are shown in Table 16. Highest scores were obtained for frozen intact corn. Moreover, the differences between intact and cut kernel samples were greater in 1977 than in 1976 and tested with greater significance. The shallower depth of cut in 1977 and the consequent exclusion of the embryo from the cut sample may account for this result. Intact ratings were also higher for canned comparisons but the differences between canned-cut and canned-intact corn were smaller and tested with less significance. The salt and sugar used in the canning "brine" probably contributed to the loss of a sensory difference.

TABLE 15. MEAN HEDONIC RATINGS FOR CUT (NORMAL) AND INTACT-SS SWEET CORN FROZEN IN 1976

Sample	Kernel type: Cut mean	Kernel type: Intact mean	Probability of significance as applied to means % t-test	Number of judges	Kernel moisture %
Golden Jubilee	6.6	7.1	0.05	43	70.5
Stylepak	6.4	7.1	0.035	36	71.5
Golden Happiness	6.5	7.3	0.02	40	73.2

TABLE 16. MEAN HEDONIC RATINGS FOR FROZEN AND CANNED, CUT AND INTACT-SS SWEET CORN PREPARED DURING 1977

Variety	Preservation method	Mean Ratings: cut	Mean Ratings: intact	Probability	T	DF	Kernel moisture %
Golden Jubilee	Frozen	6.2	7.4	0.003	4.465	27	70.5
	Canned	5.9	6.4	0.1221	1.596	27	
Stylepak	Frozen	6.2	7.5	0.001	4.465	27	72.5
	Canned	6.2	6.6	0.314	1.027	28	
Golden Happiness	Frozen	6.0	7.6	0.00001	7.864	28	73.0
	Canned	6.1	6.8	0.017	2.536	27	

Subsamples of the same 1977 lots, which were ranked hedonically above, were also presented to panels in a paired preference test. The results of this comparison are shown in Table 17; and, as expected, intact samples received the preference. Moreover, stronger preference was expressed for frozen than for canned samples. The most common reasons expressed by the panelists for preference were flavor and texture.

TABLE 17. PAIRED PREFERENCE RATINGS FOR INTACT AND CUT SWEET CORN

Variety	Preservation method	Percent preference for intact	N	Probability	Reason for preference
Golden Jubilee	Frozen	89	28	0.000027	Flavor and Texture
	Canned	64	28	0.184	" " "
Stylepak	Frozen	86	29	0.0001	" " "
	Canned	71	28	0.0356	" " "
Golden Happiness	Frozen	86	28	0.00018	" " "
	Canned	86	28	0.00018	" " "

Fiber, nitrogen, and lipid characteristics of intact and cut sweet corn kernels are reported in Table 18. No differences in Kjeldahl nitrogen were detected even though differences would be expected since inclusion of the embryo should increase the kernel protein content. Crude fiber differences between intact-SS and intact-TS kernels were small. These fiber values also reflect the order of the increasing proportion of kernels with attached cobby matter (Table 11).

TABLE 18. FIBER AND TOTAL NITROGEN IN CUT AND INTACT SWEET CORN

Kernel style	Kjeldahl nitrogen		Crude fiber		Crude fat	
	weight %	SD	weight %	SD	weight %	SD
Intact-TS	0.54	0.02	0.68	0.06		
Intact-SS	0.53	0.01	0.74	0.18	0.98	.27
Intact-HS	0.54	0.03	0.87	0.19		
Intact-DC	0.54	0.04	0.75	0.08		
Cut (1976)	0.54	0.03	0.62	0.06		
Cut (1977)	0.54	0.02	0.62	0.12	0.46	.12

The result of a comparison of the protein, which was indexed by the total amino acid content, of intact to cut kernels is shown in Table 19. The expected increase in protein for intact kernels is realized. Since the data compare amino acid contents of samples of equal mass and since there are fewer kernels per unit of mass in the intact sample, larger differences would have been indicated if the comparison had been made on a per kernel basis.

TABLE 19. TOTAL AMINO ACID CONTENT INCREASE FOR INTACT SWEET CORN RELATIVE TO CUT[a]

Variety	Percent increase in amino acid for intact kernel	Percent increase in yield for intact kernel
Golden Jubilee	15.9	27.6
Stylepak	15.6	28.1
Golden Happiness	5.5	34.8

[a]Based on equal masses of frozen samples from 1977 tests

KERNEL RESISTANCE TO DETACHMENT

Testing During 1976

The 45 x 3 test and the analysis of the resulting data assumed that kernel detachment was largely resisted by the tissues making a physiologically functional connection at the base. Values of the maximum force resisting kernel detachment calculated from 45 x 3 measurements are shown in Table 20. Differences between these values are not large with the exception of that between Vanguard and the others. Although qualitative observations agree with the position of Vanguard in this grouping, they do not agree with the position of Golden Happiness. Kernels of Golden Happiness were markedly easier to remove than the varieties with which it is closely grouped by this test.

The application of this test to individual kernel groups was subject to two types of error. One error was kernel rupture before and during detachment. The frequency of occurrence of rupture is indicated in Figure 28. Kernel sensitivity to rupture was so great that at kernel moistures higher than 76% the test could not be performed. Furthermore, rupture ended measurements before detachment and the measured force therefore underestimated the actual detachment force. Forces recorded during rupture are not included in the average values reported here.

TABLE 20. MAXIMUM TOTAL FORCE PER KERNEL MEASURED DURING KERNEL DISPLACEMENT

Variety	Rows per ear	Samples	Moisture		Force[a,b]	
			%	SD	N	SD
Golden Happiness	18	10	72.3	2.7	2.6	0.3
Golden Jubilee	18	65	71.3	4.0	2.9	0.4
Stylepak	20	40	73.2	1.8	2.3	0.3
Vanguard	18	14	70.7	1.3	3.0	1.4

(a)Reported force is value measured by 45 x 3 test divided by 3.
(b)Analysis of variance of force versus variety yields F of 8.66 which is significant at 0.003% level.

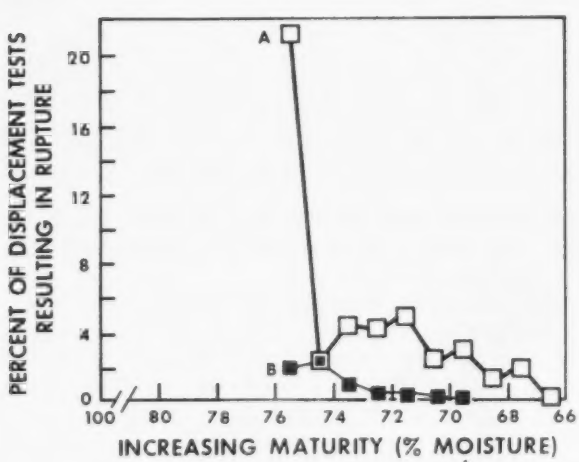


Figure 28. Kernel rupture during 45 x 3 testing (B) and 90 x 1 or 90 x 2 testing (A).

A second error source was the inability to achieve simultaneous detachment of all three tested kernels. For instance, if the displacement occurred sequentially; then, the maximum recorded force would be less than would have been recorded by simultaneous displacement.

This test was useful for interpreting the effect of heat treatment on decreasing the kernel attachment strength. For instance, early work by these authors (5) using the 45 x 3 test applied to fresh market corn of undetermined variety had shown that heat would substantially reduce the force required for kernel removal. This effect, in itself, would be desirable for ease of kernel removal and would also reduce the liquid waste during subsequent washing of the intact kernels by "setting" the starch (5). This abscission altering effect was applied in tests using frictional kernel removal described above as the textured-surface process and using freshly harvested corn. However, yields shown in Table 21 for removal of kernels from heat treated ears were lower than for untreated corn.

TABLE 21. SWEET CORN YIELD CHANGES DUE TO HEAT (5 min, 100°C STEAM) PRECONDITIONING OF EARS TO EFFECT KERNEL LOOSENING

Variety	Yield change %	SD	Condition of friction surface
Golden Jubilee	-11.2	3.7	wet(a)
Stylepak	-31.7		wet(a)
Golden Jubilee	-8.1		dry(b)
Stylepak	-11.6	1.5	dry(b)

(a)Friction surface was not heated and became wet with corn juices.
(b)Friction surface was heated to maintain dry condition.

As a consequence of these unexpected results, new 45 x 3 tests were applied to freshly harvested Golden Jubilee and Stylepak. The results for this 45 x 3 testing are shown in Table 22 and indicate that in spite of average reductions in the force resisting removal, no change and occasional substantial increases in the detachment force were found. This unexpected effect occurred twice as frequently in Stylepak as in Golden Jubilee. The inconsistency of this effect is consistent with the results of Table 21 and precludes the use of the heating method to alter the kernel attachment strength of these varieties.

TABLE 22. THERMAL PROCESSING TO ALTER STRENGTH OF KERNEL ATTACHMENT[a]

Variety	Steam exposure time	Mean reduction of detachment force		Range of reduction detachment force		Measurements with no change[b] or increase in D.F.
	min	%	SD	minimum %	maximum %	%
Stylepak	1	13	6	4	16	
	2	10	6	2	16	
	4	8	6	-16	16	38
	8	3	3	-14	19	
	12	15	15	-7	28	
Golden Jubilee	1	5	9	-6	15	
	2	13	4	8	19	
	4	11	17	-18	25	17
	8	22	13	4	40	
	12	22	9	8	34	

(a)45 x 3 Test.
(b)No change is defined here as change less than 5%.

Testing during 1977.

New qualitative observations during 1978 further challenged the validity of the base-only abscission resistance assumption of the 45 x 3 test. Two observations were made in the course of attempts to identify factors affecting the coefficient of friction between kernels and the kernel-removing friction surface, and each indicated the importance of previously neglected interkernel friction in the separation. The first observation was the discovery of the presence of microridges on the surfaces of adjacent kernels. These ridges presumably interlock and prevent a smooth, sliding separation. The second observation was the presence of a thin, waxy coating on the kernel surface. The residue from the benzene extraction of this coating was a very sticky substance which also prevented a smooth, sliding separation. Consequently, the 45 x 3 test actually measured three contributions from kernel bases and one from a side, and the ranking and results of Table 20 were held suspect.

The 90 x 1 and the 90 x 2 tests were adopted in order to identify the relative importance of abscission resistance at the kernel base and of the interkernel frictional or side resistance between kernels in the same row. The respective components were calculated from these tests.

Values of both the abscission component and the interkernel friction component shown in Table 23 indicate wide differences in each component. Abscission values differing by nearly four-fold and interkernel friction values differing by three-fold were observed.

Abscission values obtained here reflect the qualitative ease of kernel removal indicated earlier as well as qualitative observations related to Illini Xtra Sweet whose kernels are extremely difficult to detach.

Interkernel frictional resistance was so large in the Golden Happiness samples that for a substantial number of individual tests, kernels adjacent to the tested kernel(s) were also removed. This effect is numerically tabulated in Table 23 as adherence. In some instances, four or five additional kernels were detached during the intentional detachment of one (or two) kernel(s). Adherence detachment of entire kernel rows of this variety could be effected by careful manual detachment of a single kernel if the ear maturity approached that corresponding to 65% moisture. The high values of interkernel friction in Golden Happiness may be due, in part, to the absence of glume tissues since the absence of these tissues would increase the area of contact between growth ridges and between wax-covered surfaces.

The presence of strong interkernel attachment can be beneficial to the mechanical process which will be applied eventually to the high speed detachment of kernels. Two machine simplifications can be hypothesized from the genetic increase of this interkernel attachment strength. For one, alignment between kernel row and frictional separator will be less critical, since only a few kernels in each row would need to be contacted. For another, the machine itself will require less surface for contacting kernels since, in principle, detachment forces would need only to be applied at the ends or in the center and would need to be no wider than the width of one or two kernels.

The occurrence of adherence injects an additional source of error into this measurement method. For instance, during the intentional displacement of a kernel (kernel 1), the friction with the adjacent kernel (kernel 2) can reduce the "attachment" between kernel 2 and the next kernel (kernel 3). Some disruption of the abscission strength of kernel 2 can also be expected. Hence the test underestimates both components.

Kernel rupture during testing was more frequent (Figure 28) in the 90 x 1 or 90 x 2 testing than in the 45 x 3 testing. Fewer ruptures were observed during manual testing (45 x 3) since the operator can often sense or anticipate incipient rupture based on the visual appearance of the ear and can therefore reduce the rate of displacement so that rupture is less likely.

TABLE 23. MAXIMUM COMPONENT FORCES (NEWTONS (N)) MEASURED DURING KERNEL DISPLACEMENT

Variety	Number of rows	Number of samples	Moisture		Abscission force[c]		Interkernel friction force[d]		Frequency of adhesion[b]
			%	SD	N	SD	N	SD	
Golden Happiness	16	12	70.7	3.5	1.3	0.7	4.0	1.5	4.2
Golden Jubilee	18	13	70.2	2.1	3.1	1.2	2.1	1.7	0.3
Stylepak	20	22	71.5	2.4	2.3	0.7	1.5	0.8	0.4
Vanguard	18	16	73.5	4.7	3.5	1.2	1.3	1.3	0.0
Illini Xtra Sweet	16[a]	8	72.3	3.3	5.5	2.3	2.3	2.0	0.8

(a)Average result for 3 samples of 18, 3 of 16 and 2 of 14.
(b)Frequency of adhesion is the number of occurrences of displacement caused by adherence to a displaced kernel per row of kernel removal. A large number reflects strong attachment to adjacent kernel and corresponds to a large friction force (or low abscission force).
(c)Analysis of variance for abscission force versus variety yields F of 16.7 which is significant at a level not greater than 0.000%.
(d)Analysis of variance for interkernel force versus variety yields an F of 7.9 which is significant at the 0.003% level.

Effect of Maturity

Changes in the component forces due to increasing maturity were not detected in these data. Correlation of each component with percentage moisture and with solids accumulated per kernel resulted in all-variety average values for the coefficient of determination in the range of 0.1 to 0.2.

However, maturity was found to play a role in the ease of detachment when measured by rates of kernel production. As shown in Figure 29, substantial increases in kernel production rates were obtained within the range of processing maturity investigated. The data expressed by lines A (Golden Happiness) and B (Stylepak) connect points representing tests applied to corn from successive harvests of the same planting of each variety and have nearly equal slopes of 1.7 and 1.9 respectively. Golden Jubilee (C) has a slope of 3.9 but compares results from different plantings. On the basis of the base component data presented earlier these differences do not appear to be due to changes in the abscission component since the order of change shown in Figure 29 would be detectable by the test. These changes with moisture may reflect the role of pericarp strengthening as the kernel ages.

If we assume that the rate of kernel production measured in Figure 29 is related to the ease of detachment, than the ratio of the rates should be proportional to the inverse of the strength of the abscission component. This comparison of rates is made for curves A and B only since the points of C do not represent common plantings. The result of the rate comparison of Figure 29 is approximately 1.8 and the result of the inverse force comparison is 1.7.

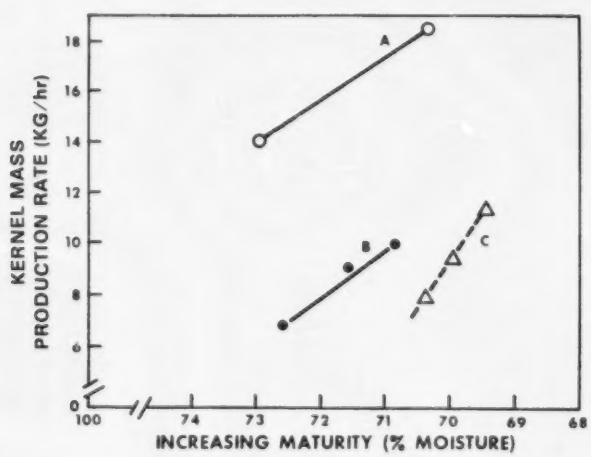


Figure 29. Rates of removal of sweet corn from Golden Happiness (A), Golden Jubilee (C), and Sytlepak (B) by friction with a moving, smooth neoprene surface.

Correlation with Kernel Removal Effectiveness

The ease of kernel removal can also be correlated with the successful removal of kernels during process tests. Data in Table 5 indicate that the order of increasing success in kernel removal agrees with the order of increasing ease of detachment; i.e. Golden Jubilee less than Stylepak less than Golden Happiness.

Theoretical Analysis

Additional insight about kernel removal can be gained by static failure analysis of the kernel itself. In this analysis it was assumed that the kernel is rigid, that stress developed in the kernel abscission layer is proportional to the applied strain, and that the only forces acting on the kernel are the applied force and reaction forces acting through biologically connected tissues.

The free body diagram for a single kernel is shown in Figure 30. Here F is the applied force, f is a fraction (0 to 1) multiplied by the kernel length l which describes the distance from kernel base to the point of application of the force, a is the length of the abscission zone (and "b" its width); R_x is the reaction force, and m is the couple providing a moment in reaction to the bending moment of F about the intersection of x - x and the kernel abscission layer.

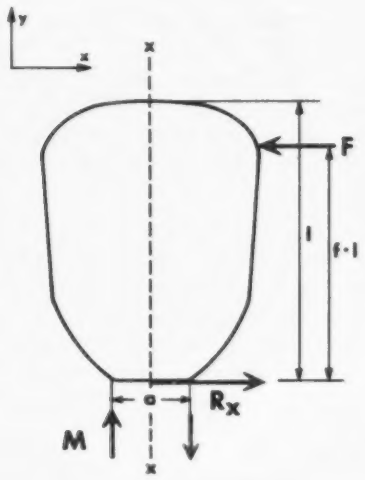


Figure 30. Schematic free-body diagram for displacement of sweet corn kernels.

By analogy to the analysis of cantilever beams (14), we identify tissue compression parallel to the fibers to the left of x - x and tension of fibers to the right. Maximum stress occurs at the surface fibers farthest from x - x and failure occurs by tension on the side of the kernel where the force is applied.

Analysis of the free body diagram further assumes that a zero stress occurs at the intersection of x - x and "a" and that the stress increases linearly to the outermost fibers. This analysis yields a force, F_D, which is applied to initiate failure.

$$F_D = \frac{\sigma_d \cdot b \cdot a^2}{6 \cdot f \cdot l} \qquad (1)$$

Here σ_d is the stress for failure by tension. By comparison, the resulting applied force, F_s, for shear failure is

$$F_s = \sigma_s \cdot b \cdot a \qquad (2)$$

where σ_s is the stress for shear failure. Estimation of the mode of failure is made by forming the ratio of F_D to F_s. If this ratio is <1 then failure occurs by the mode corresponding to F_D. The ratio is

$$\frac{F_D}{F_s} = \frac{\sigma_d \cdot a}{6 \cdot \sigma_s \cdot f \cdot l} \qquad (3)$$

and by substituting σ_s/σ_d equal to 0.06 (15) as measured for wood (an analagous conducting tissue) and a/f·l equal to 0.1, the value of the ratio F_D/F_s is 0.3; hence, failure would be expected to occur sooner by bending than by shearing. Observations during this testing program confirmed this analytical result. (The reader should note that this force analysis neglects the influence of a y-component of force, the effect of which will depend on the position of the kernel surface at which the detaching force F is applied. For instance, if F is applied to the right of x - x then the moment M will be decreased and F required for detachment is increased. If the resultant is applied to the left of x - x, then M is increased and F required for detachment is decreased.)

Furthermore, on the basis of this analysis we can expect that varieties of sweet corn with long kernels or small abscission layers will require less force for detachment than varieties with short kernels and large abscission layers provided the stress for tensile failure is identical. The varieties tested did not differ greatly in length measured from crown to point of abscission. Values of mean kernel length were 1.23 $\pm$ 0.08 cm SD for Golden Jubilee, 1.23 $\pm$ 0.05 cm SD for Stylepak, 1.28 $\pm$ 0.12 cm SD for Golden Happiness, 1.19 $\pm$ 0.08 cm SD for Vanguard, and 1.22 $\pm$ 0.04 cm SD for Illini Xtra sweet. Analysis of variance yielded an F of 2.24 which is significant at the 7.5% level. The data may be ranked approximately by order of increasing kernel length and decreasing abscission force with only Illini Xtra Sweet out of order and with Jubilee and Stylepak approximately equal in the length ranking. The geometry of the kernel abscission zone was not measured.

The results of 45 x 3 and 90 x 1 - 90 x 2 tests may be resolved if an accounting is made of two competing factors which would detract from the comparison. The first factor relates to the point of application of the force in each test. Since the 45 x 3 is applied at or near the kernel crown, f = 0.9 to 1.0, and the 90 x 1 is applied centered at f = 0.67, a correction factor of 2/3 is introduced in computing 45 x 3 values from 90 x 1 and 90 x 2 measurements. The second factor relates to the angle at which the strain was applied. Since the x-component of the measured (45 x 3) which causes displacement is related to the total applied force by sin ($\pi/4$), a correction factor of $(\sin \pi/4)^{-1}$ or 1.4 is applied. The multiplied correction factors yield a factor of 0.94 to be applied to the 90 x 1 and 90 x 2 results.

When the calculation of the expected 45 x 3 result is made from measured 90 x 1 and 90 x 2 tests, the values of calculated per kernel forces (Table 24) compares favorably with the measured values with the exception of the values for Golden Jubilee. At any rate, the calculated force would have been expected to be higher than the measured force since the simultaneous displacement of three kernels is difficult to achieve. Displacements occuring sequentially would be expected to reduce the maximum observed values.

TABLE 24. COMPARISON OF PER-KERNEL FORCE BY ACTUAL 45 x 3 TESTS TO FORCE BY COMPUTED 45 x 3 TESTS BASED ON COMPONENT ABSCISSION AND INTERKERNEL FRICTIONAL FORCES IN 90 x 1 OR 90 x 2 TESTS

Variety	Measured 45 x 3 per kernel force[a]		Total calculated 45 x 3[b]	
	N	SD	N	SD[c]
Golden Jubilee	2.9	0.4	3.5	1.3
Golden Happiness	2.6	0.3	2.5	0.9
Stylepak	2.3	0.3	2.6	0.8
Vanguard	3.0	1.4	3.7	1.3

(a)Measured during 1976.
(b)Based on data from 1977.
(c)Compound standard deviation.

REFERENCES

1. National Canners Association 1971. Liquid wastes from canning and freezing fruits and vegetables. EPA Program Number 12060EDK, p. 144.
2. Inglett, G. E. ed. 1970. Corn: Culture, Processing, Products. AVI Publishing Inc., Westport, Conn.
3. Huelsen, W. A. 1954. Sweet Corn. Interscience Publishers, Inc. New York, N.Y.
4. Lockwood, D. H. and Andres, C. 1977. Modified starch assures stability, long shelf life, consistency of cream style corn. Food Proc.: (6) 76-77.
5. Robertson, G. H., Lazar, M. E., Galinat, W. C., Farkas, D. F. and Krochta, J. M. 1977. Unit operations for generation of intact or unit kernels of sweet corn. J. Fd. Sci. 42:(5)1290-1303.
6. The Association of Official Agricultural Chemists. 1965. Official Methods of Analysis, 10th ed. The Association, Washington, D.C. p. 308.
7. National Canners Association. 1968. Laboratory Manual for Food Canners and Processors. AVI Publishing Co, Inc., Westport, Connecticut. Vol. 1, Chapters 8 and 9.
8. United States Environmental Protection Agency. 1971. Methods for Chemical Analysis of Water and Wastes. EPA-16020-07/71. Environmental Protection Agency, Washington, D.C.
9. The Association of Official Agricultural Chemists. 1975. Official Methods of Analysis, 12th ed. The Association, Washington, D.C. p 15. Method 2.049.
10. The Association of Official Agricultural Chemists. 1975 Ibid. p 137, Method 7.054.
11. The Association of Official Agricultural Chemists. 1975 Ibid p 135, Method 7.044.
12. Peryam, D. R. and Girardot, N. F. 1952. Advanced taste-test method. Food Eng. 24: 58.
13. John, J. 1976. Private communication. United States Department of Agricultural, Agricultural Market Service, USDA, 111 W. St. John St, Suite # 416, San Jose, CA 95113.
14. Seeley, F. B. and Smith, J. O. 1956. Resistance of Materials. 4th ed. John Wiley, New York, p 459.
15. Perry, R. H., (Ed.), 1967. Engineering Manual. 2nd ed. McGraw-Hill Book Company. N.Y. p. 6-60.
16. Gacula, M. C., Moran, J. M., and Reaume, J. B. 1971. Use of the sign test in sensory testing. Fd. Prod. Dev. 5(6), 98.
17. Galinat, W. C. 1979. On the usage of the terms pedicel and rachilla in description of the cob, the female spikelet and the grain in maize. Maize News Letter, in press.

APPENDIX 1. WASTE INDICES

The measures of liquid waste strength applied to the wash and blanch effluents encountered in this study were biological oxygen demand (BOD), total organic carbon (TOC), chemical oxygen demand (COD), total solids (TS), and suspended solids (SS). Since the application of all of these measures is time consuming and costly, the data were analyzed to establish correlations between the measures so that one or two simple tests could be used for reporting purposes and for the analysis of additional experiments.

The result of these correlations is shown in Table A1. Here BOD, COD, TS, and SS are correlated with TOC. Excellent correlations of BOD, COD, and TS were obtained. Correlation of SS with TOC was not good but was improved when the data were grouped according to their point of origin from the blanching or washing stages. Since suspended solids do not necessarily represent all of the effluent generated, the SS correlation with TOC should not be expected to be strong. However, the strong correlation between COD, BOD, and TOC was used to support the use of TOC as the preferred measurement method during 1977. Data from 1977 are reported in the text as COD as calculated using the regression formula.

TABLE A1. CORRELATION OF WASTE INDICES (I) WITH TOTAL ORGANIC CARBON MEASUREMENT. (I = A (TOC) + B).

Index	Data base year	Regression constants		Coefficient of determination
		A	B	
BOD	1976	1.27	-46.9	0.980
COD	1976[a]	2.67	-12.8	0.997
TS	1976	2.24	71.7	0.992
TS	1977	2.52	-73.0	0.995
SS	1976[b]	0.16	151	0.294
SS	1977	0.32	344	0.565
SS	1977[c]	0.311	-45.5	0.81
	1977[d]	0.704	-137	0.88

(a)Excludes samples with salt residuals >0.5% from brine flotation prior to blanch.
(b)See note (a), also excludes blanch.
(c)Blanch only.
(d)Wash only.

APPENDIX 2. PRELIMINARY CANNING STUDIES

Stationary Retort

Heat penetration studies were conducted on intact and cut corn kernels packed in a 4%-sucrose 2%-NaCl solution in 303x406 tin cans. Data obtained from the Technical Service Corporation, which provides this service regularly to member canners, are shown in Table A2. In that a slightly shorter cook is required, some advantage is indicated here for the recommended processes for intact kernels. This effect reflects the differences in the respective kernel matrices in the can. In the case of the cut corn, the kernels tend to pack more closely together so that the brine does not circulate freely to convect heat through the matrix; hence, the center is heated more slowly. In the case of the intact kernels, the kernels pack more loosely so that there is greater freedom of movement of the heated solution within the can, and the center is more quickly heated.

TABLE A2. RECOMMENDED STATIONARY-RETORT PROCESSING CONDITIONS[a]

Kernel type	Heat penetration curve parameters (min)				Initial temperature		Time (min) at retort temperature	
	j	fh	f_2	X_{bh}	°F	°C	240°F (116°C)	250°F (121°C)
cut	0.909	-6.6	-18.1	8.26	70	21	43	21
					90	32	42	21
					110	43	41	20
					130	54	41	19
intact	-0.772	5.5	17.4	-7.26	70	21	40	19
					90	32	39	18
					110	43	39	17
					130	54	38	17

[a]Reference 7.

Agitated Retort

Heat penetration studies were also conducted in a laboratory agitated retort and are reported in Table A3. Intact kernels required slightly shorter processing times.

TABLE A3. RECOMMENDED AGITATED-RETORT PROCESSING CONDITIONS[a]

Kernel Type	Heat penetration curve parameters (min)					Initial Temp.		Time (min) at retort temperature of		
	j	f_h	f_2	f_c	X_{bh}	°F	°C	240°F (116°C)	245°F (118°C)	250°F (121°C)
cut	1.164	4.72	6.40	4.72	6.76	80	27	42	26	18
						100	38	42	26	18
						120	49	42	26	17
						140	60	41	25	17
intact	1.309	3.60	4.67	3.60	2.45	80	27	41	25	17
						100	38	41	25	17
						120	49	41	25	16
						140	60	40	24	16

[a]Reference 7.